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Image Gradation, Graininess and Sharpness in Television and Motion Picture Systems

Part II : The Grain Structure of Motion Picture Images—An Analysis of Deviations and Fluctuations of the Sample Number

By OTTO H. SCHADE

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Presented by Otto H. Schade, Tube Dept., Radio Corporation of America, Harrison, N.J., in part on April 20, 1950, at the Society's Atlantic Coast Section Meeting at New York, and on May 3, 1951, at the Society's Convention at New York. Portions of this paper have been made available to the Subcommittee on Distribution Facilities, Theater Television Committee of the SMPTE, in the form of three reports: (1) "Random Fluctuations in Television and Motion Pictures," June 7, 1950; (2) "Outline and Results of a Study to Determine Television System Parameters Providing an Image Sharpness Equivalent to a 35-Millimeter Motion Picture Process," May 15, 1951; (3) "Theater Television Transmission Channel: Choice of Performance Factors," May 31, 1951.

Note: Part I of this paper, "Image structure and transfer characteristics," was published in this *Journal* in February 1951, pp. 137–171.

SYMBOLS

Note: Peak values are designated by a peak sign over a symbol, $\hat{B}$; and average or mean values by a horizontal bar, $\bar{n}$.

a	Area of sampling aperture
Δa	Incremental portion of a
$\bar{a}$	Mean value of response factor $r_{\bar{\psi}}$ in incremental section ΔN
A	Frame area
B	Luminance
c	A constant
D	Total density of photographic film; D_1 density of negative film, D_2 density of positive film
D^*	Density above base density
E	Exposure (unit: meter candle seconds)
f	Frequency; $f(x, y)$ a function of x and y
H	Horizontal dimension of picture frame
k	A constant
l	Unit of length
N	Line number = number of half-wave lengths of line- or sine-wave patterns per length unit
N_c	Limiting resolution
$N_e N_e^*$ $\overline{N_e}$	Equivalent passbands (Eqs. (22) to (28))
$\overline{N_e}$	Equivalent passband of an asymmetric aperture (Eq. (23))
N_r	Rated resolving power of film ($r_{\bar{\psi}} \simeq 0.02$)
N_δ	Line number indicating aperture diameter (Eq. (19))
n	Number of particles or samples inside of sampling area
Δn	Deviation from average number $\bar{n}$; $\Delta n = n - \bar{n}$
$[\Delta n]$	Rms value of deviation
r_a	Characteristic radius of an aperture
$r_{\bar{\psi}}$	Sine-wave response factor (Eq. (18))
$[R]$	Signal-to-rms-deviation ratio static value in a single image frame (Eq. (13))
$[R]_\tau$	Signal-to-deviation ratio of film transmittance (Figs. 49–52)
$[R]^*$	Signal-to-deviation ratio neglecting lens flare and ambient light
$[R]_{12}$ etc.	Signal-to-deviation ratio of a process. The index 1 is used for deviations originating in a negative film process; the index 2 for a positive film process; the index 0 for a process (lens) preceding the negative; the index 3 for a process (lens) following the positive. An index 13 indicates deviations originating in 1 and observed after the processes 2 and 3.
$[R]_\alpha$	Luminance fluctuation ratio, dynamic value (Eq. (47))
s	Length of side of square aperture, or storage factor
T_f	Frame time
T_s	Storage time (Eq. (47))
u	A characteristic length unit used in aperture calculations
V	Vertical frame dimension
x, y	Coordinates, x = coordinate in the direction of scanning
Y	Amplitude, intensity
γ	Constant gamma
$\dot{\gamma}$	Point gamma, definition in Part I, p. 145. A single index number indicates the process as stated under $[R]_{12}$; a combination index ($\dot{\gamma}_{12}$) indicates the product $\dot{\gamma}_1\dot{\gamma}_2\dot{\gamma}_3$.
δ	Characteristic aperture diameter (index system as for $[R]$)
ϵ	Base of natural logarithm
τ	Transmittance
σ	Relative deviation (Eqs. (13) to (17))
$\bar{\psi}$	Flux
$[\bar{\psi}]$	Rms value of variational (a-c) flux (see Eq. (20))
$\bar{\psi}$	Average (d-c) flux
$\bar{\psi}_0$	Zero "frequency" component of flux (see Eqs. (18) and (21))
$\bar{\psi}_0$	A light bias (see discussion of Eq. (38))

SUMMARY OF PART II

An objective measure of the luminance deviation caused by the random structure in motion picture and television images is developed, based on the distribution and a count of the number of grains or electron "samples" in a specified sampling area. The "effective sampling area" of the various components in photographic or television systems is determined from their response to sine-wave test signals and specified by an equivalent measure N_e. The accuracy of this method is compared with a direct evaluation from the dimensions of the point image or resolving "aperture" for which the geometrical properties are

known. The law of sample distribution at the sources of the deviations in motion picture systems is investigated and methods are developed for computing the relative deviation and the "frequency" spectrum in the entire luminance range of the projected image as modified by successive aperture-response and nonlinear transfer effects. Numerical evaluations of a number of motion picture processes are carried out and a discussion is included of optimum conditions for video recording and possibilities for improvements.

Part II is limited to a treatment of aperture-response theory as applied to the evaluation of the relative deviation in motion picture processes. Part III, to be published later, will treat the raster effect, the apertures and the relative deviation ("noise"-to-signal ratio) in television systems, followed by an interpretation of graininess which includes the process of vision. The aperture theory and use of the measure N_a will be developed further in Part IV which will deal specifically with methods and measurements for evaluating resolution, definition and sharpness of images.

A. DYNAMIC FLUCTUATIONS AND STATIC DEVIATIONS

Continuity of contours and uniformity of tone values in an image are in reality illusions created by a limited perception of fine detail, an inability to count or resolve the individual "samples" of energy or matter forming the image. This limitation can usually be removed when a small area a is inspected under high magnification. Suppose the number n of samples arriving in this "sampling area" or passing through a "sampling aperture" placed over a live image is counted during a time unit. The number n obtained in various counts will be found to *fluctuate* around an average value $\bar{n}$ which does not change when the sampling area is moved to different locations in a larger area representing a uniform intensity. The fluctuations in different positions of the area a, however, are generally found to be nonsynchronous. In a "live image" from a lens, television tube or motion picture film, these fluctuations in the number of light samples are fluctuations of luminance which give the impression of a moving granular structure.

In most reproduction processes the light samples in a live image are converted, accumulated, and stored in special image surfaces during a given (exposure) time in the form, for example, of silver grains or electron charges. Such an *image frame* is, therefore, a static record of the number and distribution of effective samples collected during the exposure time. A single "frame" does not show dynamic fluctuations but exhibits static *deviations* in the number of samples between sampling areas.

The *static deviation* in a sample arrangement representing a constant density can be evaluated statistically by counting the samples (grains, electrons) in a sampling area a which is moved to various positions, determining the mean value $\bar{n}$ of the readings, and tabulating the deviations in number Δn from the mean value $\bar{n}$. The rms value $[\Delta n]$ of the deviations is known as the standard deviation. The ratio of the standard deviation to the mean value is the *relative deviation* σ; its reciprocal is the "*signal-to-deviation*" *ratio* $[R]$. The two ratios are defined by the equation:

$$\sigma = 1/[R] = [\Delta n]/\bar{n} \qquad (13)$$

When the samples in an image frame are distributed with uniform probability independently of one another, and when the area occupied by a sample is small compared to a, the average number of samples counted in a sampling aperture of uniform transmittance is proportional to its area a

$$\bar{n} \propto a \tag{14}$$

The rms deviation $[\Delta n]$ is found to follow the law

$$[\Delta n] = (\bar{n})^{\frac{1}{2}} \tag{15}$$

and the relative deviation (Eq. (13)) for this distribution is, hence,

$$\sigma = (\bar{n})^{-\frac{1}{2}} \tag{16}$$

This relation changes inversely with the square root of the sampling area:

$$\sigma \propto a^{-\frac{1}{2}} \tag{17}$$

A distribution with these characteristics will, henceforth, be referred to as a *random* distribution. This distribution can be verified by testing the validity of Eqs. (15), (16) and (17) by a sampling process. A grain structure containing samples of several sizes has a random distribution when the distribution for each sample size is random as specified above. The definition holds also for a structure which can be considered as a linear superimposition of a number of sample layers, each having a random distribution.

B. PHYSICAL SAMPLING APERTURES FOR RANDOM AND CONTINUOUS SAMPLING PROCESSES

The random step-wise selection of sampling positions in static-deviation measurements (discussed in the Appendix to this Part) can be replaced by a continuous displacement of the sampling aperture. When, for example, the grain structure of an illuminated film of constant density is "scanned" by an aperture, the light flux passing through the sampling aperture into a phototube is a relative measure of the grain number n and causes a current, fluctuating in amplitude around an average value. The total current may be shown by an oscillograph or recorded by a microphotometer; its average value (signal) as well as the rms deviation (a-c component) can be measured directly by suitable current meters.

In both step-wise or continuous deviation measurements the total flux, i.e., the number of samples integrated or "counted" within a sampling aperture of *uniform transmittance*, is proportional to the *area* of the aperture. The aperture *shape* is, in principle, unimportant (barring diffraction or diffusion) because any odd-shaped aperture of uniform transmittance can be assembled from a number (ζ) of small apertures Δa of equal size, which may be arranged in any desired shape.† When the grain distribution is random, as specified above, there is no correlation or preferred sequence of grain occurrences when the grain pattern is sampled or scanned. A round sampling aperture, however, is advantageous because it reduces undesired optical effects (diffraction) to a minimum.

In contrast to the above, the shape of a scanning aperture analyzing or *forming pictorial images* or images of test charts can be of importance, because these images may consist of sample arrangements with definite preferred locations (straight or curved contours), according to the subject material. Sampling apertures with circular symmetry are preferred for simultaneous imaging and are used also as scanning apertures in television systems.

Comparison of a graph of sample readings taken at random from a grain pattern with a microphotometer trace shows that there is a considerable difference in the *sequence* of values ob-

† The relative deviation for an area $a = \zeta \Delta a$ is simply $\sigma = \sigma_1/\sqrt{\zeta}$, with σ_1 = relative deviation of Δa.

tained by random step-wise sampling as compared to the conditioned sequence of amplitudes in a waveform obtained by a continuous displacement of the same sampling aperture over the same grain pattern.

The average value (d-c signal) of the graph or waveform and the rms deviation, however, are unchanged when a sufficient number of sampling points has been taken. The signal-to-deviation ratio [R] can, hence, be determined accurately by random or continuous sampling with an aperture.

C. METHOD OF EVALUATING THE EFFECTIVE SAMPLING AREA OF AN UNKNOWN APERTURE

The standard deviation has obviously no meaning when the size of the sampling aperture remains unknown or unspecified. When deviations are imaged, i.e., transferred, through an imaging system, the components (lens, film) of the system cause an integration of samples within the area of their point image (star image). The point image which has been identified as the "resolving aperture" of the device, represents, therefore, the sampling aperture of the device referred to the image plane. The equivalent area a of this aperture must, hence, be known for all system components in order to evaluate signal-to-deviation ratios.

It is difficult and in many cases impossible to measure the sampling aperture of a system component directly, but it is relatively simple to analyze the aperture effect in images made of suitable test objects. According to a Fourier theorem the complex waveform obtained by the scanning of a random structure can be broken down into a continuous spectrum of constant-amplitude sine-wave components which, for this purpose, can be regarded as having equal amplitudes and random phase relation. This sine-wave spectrum does not extend to infinity, but the sine-wave amplitudes may be assumed as constant over a wide range of wavelengths usually extending far beyond the limiting resolution of the first sampling aperture. It is thus expected that the integrating effect of a sampling aperture on fluctuations can be synthesized from the aperture effect on single sine-wave components determined with a series of test patterns, each representing a sinusoidal flux pattern of one constant optical sine-wave length in the image field. When the shape and passband of the sine-wave response characteristic of the unknown aperture are compared with those of known aperture types (round, cosine squared, exponential, etc.), an exact or an equivalent aperture area can be established for the particular device or for an entire process. It appears advisable at this point to define units and terms, particularly the meaning of optical sine waves, line numbers, and passbands.

1. Units and Terminology

The conventional optical test pattern consists of groups of sharply defined adjacent bars, alternately black and white and of equal width. The width of the bars decreases from group to group. These patterns are optical *square-wave flux patterns* having decreasing square-wave lengths. Variable-density recordings of electrical sine-wave signals on the sound track of a motion-picture film accordingly represent optical *sine-wave flux patterns* (see Fig. 40). Optical patterns always have and must have two dimensions to be useful for measurements with two-dimensional apertures. For a study of the sine-wave response of an aperture in one direction, the test pattern must

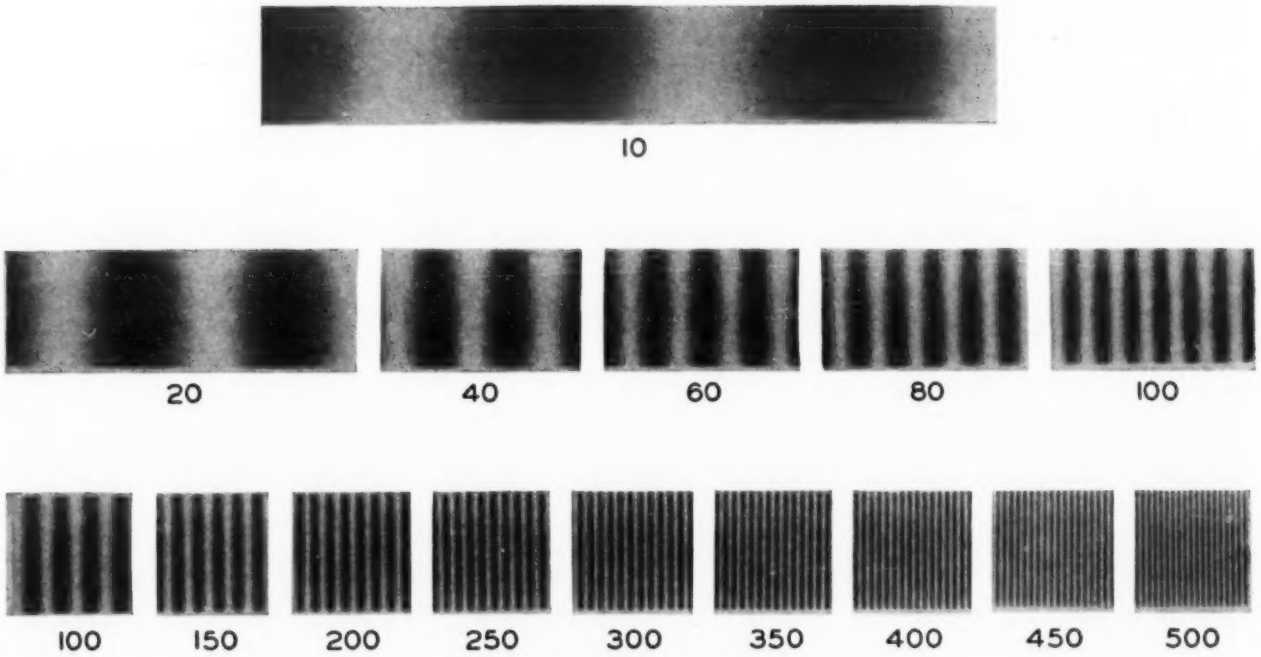


Fig. 40. Optical sine-wave test pattern.

give a flux distribution varying sinusoidally in one direction of the field but remain uniform in the perpendicular direction, appearing to the eye as a series of parallel dark and light bands or lines (Fig. 40). When imaged by an aperture (lens, film) or scanned by an aperture (perpendicular to the lines) the reproduced flux pattern or the flux signal from the aperture is again a pure sine-wave pattern or signal, but with reduced amplitude which may be computed or measured as a function of the sine-wave length in the optical test pattern. When measuring optical wave patterns the unit is obviously a length. Its reciprocal in analogy with electrical terms, is an "optical frequency" stating the number of waves per length unit (not time). In television terminology one full wave in the test field consists of two half-waves, the positive half-wave being identified as a light "line" and the negative half-wave as a dark "line," thus leading to the definition: *the line number N specifies the number of half-waves per reference length.* The television unit will be used throughout this paper unless stated otherwise. The television unit is smaller by a factor of two than the photographic unit which identifies one line with one complete wavelength.†

The sine-wave flux response is specified in relative units by the *sine-wave flux response factor* $r\Psi$, defined as the ratio of the sinusoidal aperture flux Ψ_N at a line number N to the sinusoidal aperture flux Ψ_0 at a line number N approaching zero as a limit.

$$r\Psi_N = \Psi_N/\Psi_0 \qquad (18)$$

The response factor $r\Psi$ is single valued and *independent of the test-pattern contrast* provided waveform distortion by nonlinear transfer characteristics is avoided by restricting the "signal" amplitudes (contrast) from the test pattern to appropriate values. The *optical passband* of the aperture is the range of line numbers from $N = 0$ to $N = N_c$ in which the aperture response $r\Psi$ decreases from unity to zero. It is emphasized that, strictly speaking, this passband describes the aperture response in one direction only, the direction of scanning. Apertures of circular symmetry have but one response characteristic and passband for all directions, while asymmetric apertures (squares, slits, etc.) have many response characteristics and optical passbands depending on the aperture orientation relative to the direction of displacement. Description of an asymmetric aperture by its aperture response requires at least two characteristic passbands (vertical and horizontal) which for some purposes can be replaced by the passband of an aperture with circular symmetry and equivalent area a (see Sec. 3 below).

2. Aperture Response Characteristics

The "aperture response" of optical devices is usually observed on square-wave line patterns. The sine-wave response can be derived from the square-wave flux response or may be measured directly as will be described in Part IV which will deal specifically with the subjects of resolution and aperture response characteristics and a new system of rating based on the measure of equivalence developed in the following section. The sine-wave response factor r_Ψ has been computed for various sampling apertures and is shown in Figs. 41 to 46a.

The line number for these aperture types is expressed in relative units N/N_δ which refer to a characteristic aperture diameter

$$\delta = l/N_\delta \qquad (19)$$

where l = unit of length (l = 1 milli-

† When the number of lines in a background other than black or white is specified, the photographic definition of counting only one of the two distinct lines in the pattern appears less descriptive than the television definition which applies to all cases.

meter, or $l = V$ = vertical dimension of frame). The line number N_δ specifies the condition at which the length of one half-wave in an optical sine-wave pattern equals the characteristic aperture diameter δ. Sharply defined apertures have response characteristics (Figs. 41 and 42) exhibiting an oscillatory decrease of the response factor with several zero values and 180° phase change at every zero value, indicated in the drawings by a change of direction.

Grain structures such as in photographic film or kinescope phosphors do not, in general, form an infinitesimal image of a mathematical point of light and, therefore, have an aperture effect. When a grain layer of finite thickness is

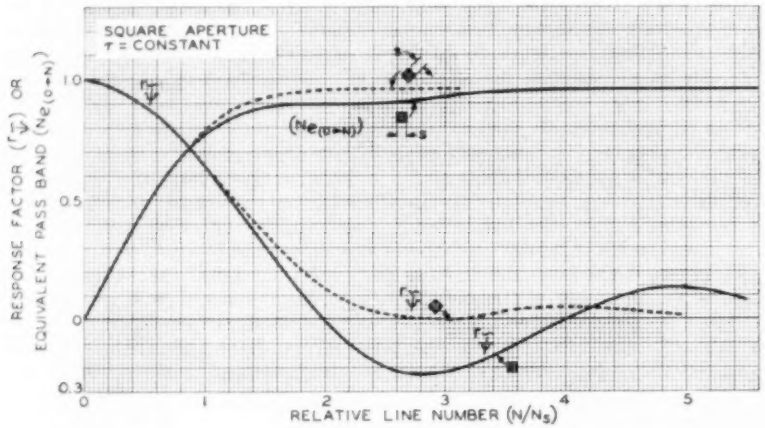


Fig. 41. Sine-wave response characteristics of square aperture.

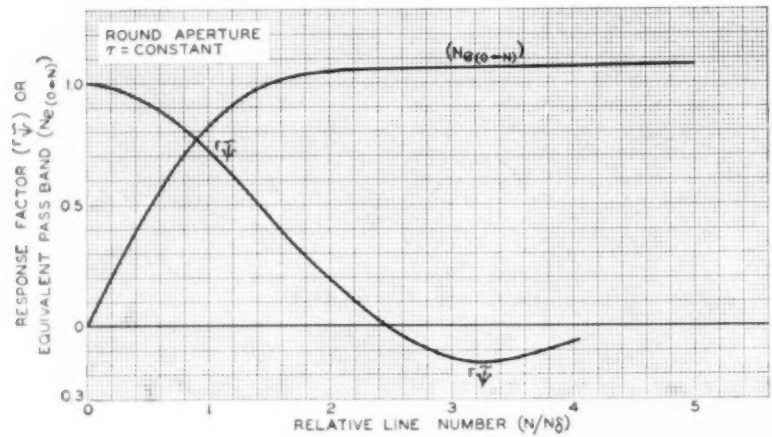


Fig. 42. Sine-wave response characteristics of round aperture (τ = const.).

exposed to an infinitesimal pencil of light (or electrons), diffraction, diffusion, and progressive absorption of light cause an exponential spreading of light in the grain layer, leading to the hypothesis that the point image of the structure has the form of a round "aperture" with exponential transmittance $\tau = \epsilon^{-r/r_o}$. The sine-wave response computed for this theoretical equivalent, is shown in Fig. 46a in relative units N/N_δ for a diameter $\delta = 6r_o$.

Photographic film is exposed to light twice, once during exposure, and then again upon projection of the developed image. The main aperture effect of its grain structure occurs during exposure in the *undeveloped semitransparent*

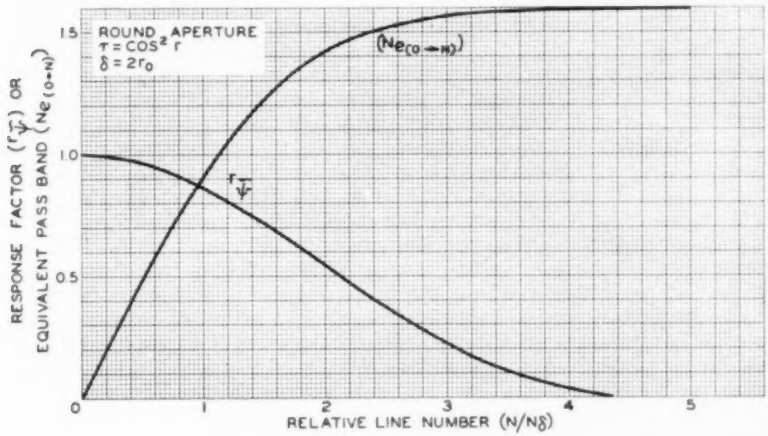


Fig. 43. Sine-wave response characteristics of round aperture ($\tau = \cos^2 r$).

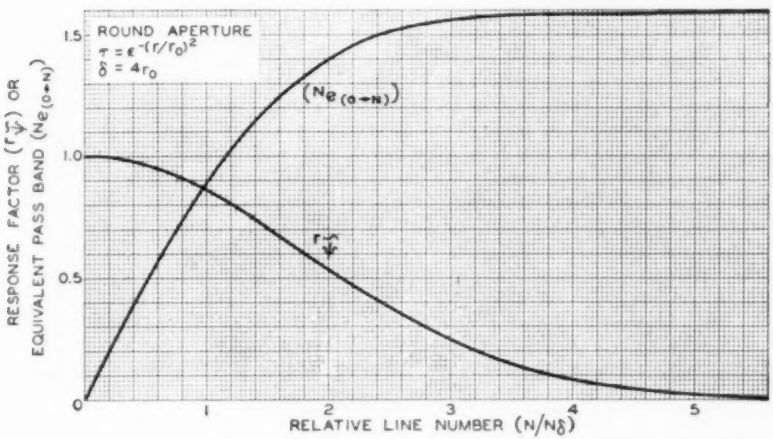


Fig. 44. Sine-wave response characteristics of round aperture ($\tau = \epsilon^{-(r/r_o)^2}$).

state of the structure. The second aperture effect occurs in the transmission of light through the *developed* grain structure in printing or projection processes and is of much smaller magnitude because of the high absorption of light in the "black" silver grain structure. The total aperture effect of photographic film is, therefore, caused by large and small exponential aperture in cascade, dominated by the first aperture effect during exposure. It is thus found that the sine-wave response measured with an electronic microphotometer[1] on test patterns photographed on a variety of films, or optically projected onto kinescope phosphors with various grain sizes, mixtures and thicknesses, is closely

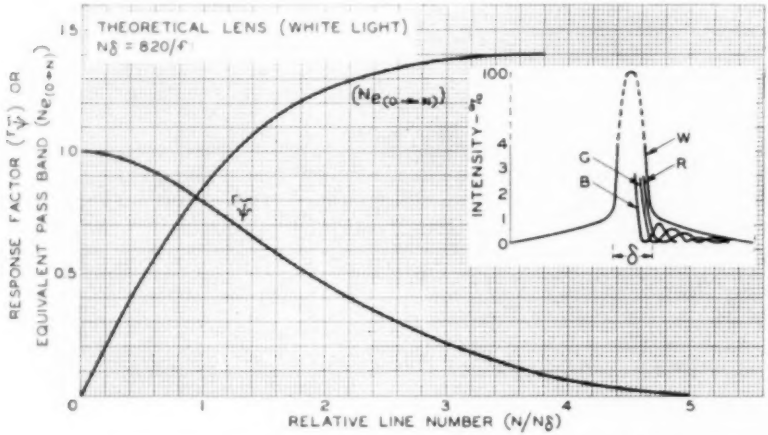


Fig. 45. Sine-wave response characteristics of theoretical lens (white light).

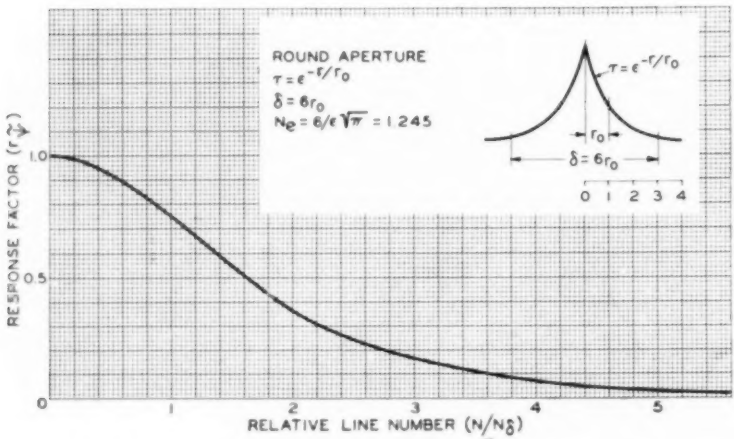


Fig. 46a. Sine-wave response characteristics of mathematical equivalent aperture of grain structures.

represented by the normalized response characteristic Fig. 46b. Exposures representing large signals may lead to waveform distortion which depends on the linearity of the transfer characteristic of the process. These effects can be determined separately by the same methods used in electron-tube evaluations. The rated resolving power N_{cr} of film is found to correspond to a response factor r_ψ of roughly 2%. For want of a better reference value, the rated resolving power N_{cr} has been chosen as the reference unit. Comparison of the theoretical and measured characteristics (Figs. 46a and b) shows them to be almost perfect duplicates when N_{cr} is placed at $N/N_b = 5.17$ in Fig. 46a. It is emphasized that the sine-wave response characteristic of a grain structure is not a measure of its particle size or its granularity and is single-valued in a linear system. Small signals, therefore, should be used when photographic film is measured as pointed out above.

The sine-wave response characteristic of a number of aperture processes in cascade can be computed accurately. *The overall response factor at any given line number N is the product of the response factors of the system components at that line number.* The use of sine-wave test patterns avoids the indirect quadratic addition of line numbers required for cascading square-wave characteristics[1] because, unlike the square-wave flux response which contains harmonic frequencies, the sine-wave flux response retains a pure sine-wave form throughout the system.

3. Evaluation of an Equivalent Passband N_e and a Characteristic Aperture Dimension From the Sine-Wave Spectrum

The sine-wave components in a source of deviations, such as an illuminated random grain structure, may be determined by a Fourier analysis of the complex waveform obtained by scanning the source with an infinitesimal aperture. The amplitude and flux of the various sine-wave components can be considered alike and constant, the components filling a continuous spectrum up to a very high line number, as illustrated by Fig. 47a. Integration of random deviations by a scanning aperture of finite

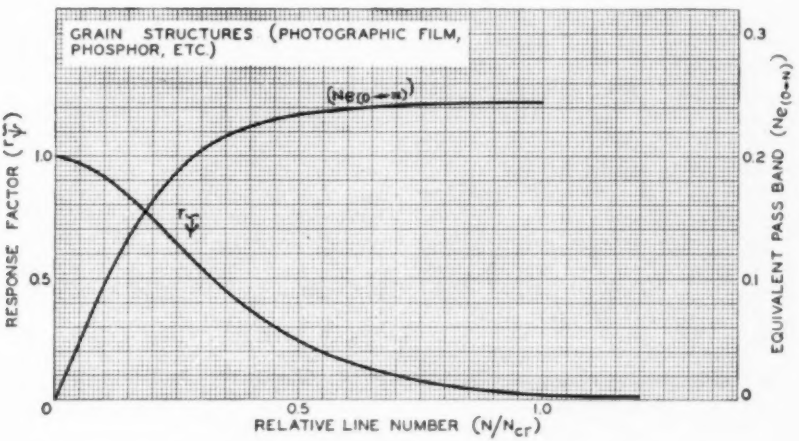


Fig. 46b. Sine-wave response characteristic structures of grain structures (measured).

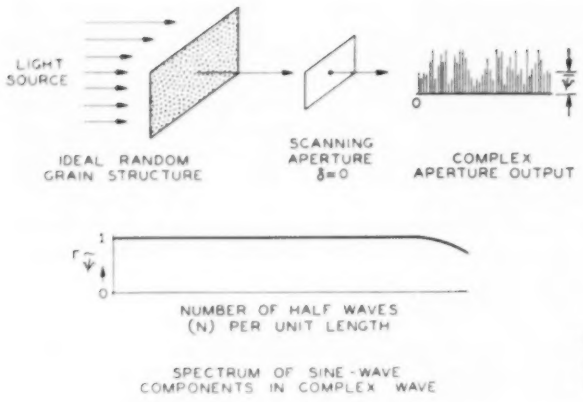


Fig. 47a. Fourier components of ideal random grain structure.

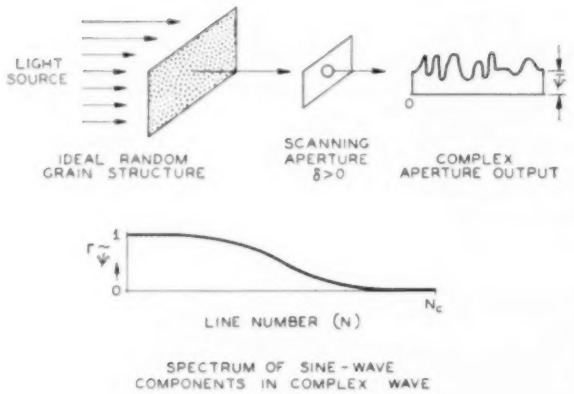


Fig. 47b. Fourier components of random grain structure after an aperture process.

size results in a distribution of flux components and a limited sine-wave spectrum of the type shown in Fig. 47b.

The relative deviation resulting from the scanning of an ideal random structure with an aperture is related to the total response of the aperture by the equation

$$\sigma = [\phi]/\bar{\phi} = [{}_0\!\int^{\infty} \phi^2_N dN]^{\frac{1}{2}}/\bar{\phi} \quad (20)$$

The value $\bar{\phi}$ represents the average value of the total flux; i.e., its d-c component. The value $[\phi]$ is the rms value of the total (a-c) flux variation given by the $\frac{1}{2}$-power of the integral of squared sine-wave flux deviation components.

When the sine-wave response is normalized according to Eq. (18) so that $\phi_N = 1$ at $N = 0$, the mean squared flux variation or deviation is expressed by

$$[\phi]^2 = \phi_0{}^2{}_0\!\int^{\infty} (r\phi)^2_N dN \quad (21)$$

where $r\phi_N$ is the sine-wave response factor and ϕ_0 measures the magnitude of the (a-c) flux component passing through the aperture with a line number N approaching zero as stated by Eq. (18). A hypothetical aperture having a con-

stant response ($r\psi = 1$) from $N = 0$ to a line number N_e^* where the response drops abruptly to zero, would give a mean squared deviation

$$[\psi]^2 = \psi_0^2 N_e^*$$

The integral of squared response factors in Eq. (21) may hence be interpreted as a normalized mean squared deviation or an *equivalent passband* of constant amplitude extending to the line number N_e^* as defined by

$$N_e^* = [\psi]^2/\psi_0^2 = {}_0\int^\infty (r\psi)^2 N dN \qquad (22)$$

The measure N_e^* has the dimension: length^{-1}. Its reciprocal value expresses an equivalent length or diameter of the aperture *in the scanning direction*. Like the aperture response, N_e^* depends, in general, on the aperture orientation relative to the direction x of aperture displacement. Apertures with circular symmetry have a single effective length proportional to their diameter δ and a single value N_e^*. Elliptical or rectangular apertures can be specified by two values $N_{e(a)}^*$ and $N_{e(b)}^*$ obtained by orienting their major or minor dimensions (a or b) in the direction of scanning. These two values can be combined into a single value

$$\overline{N}_e^* = (N_{e(a)}^* N_{e(b)}^*)^{\frac{1}{2}} \qquad (23)$$

representing an equivalent symmetric aperture.

The direct evaluation of the measure N_e^* for an unknown aperture requires a calibrated random grain pattern which must be tested by a harmonic analysis of the complex aperture output. A practical alternative is a synthesis of the sine-wave characteristic from the aperture response to constant amplitude sine-wave patterns of various wavelengths and an evaluation of N_e by Eq. (22). Optical sine-wave patterns consisting of parallel "lines," however, do not duplicate exactly the sine-wave components in a random flux pattern, but rather in a pattern which is random only in the direction x of scanning and uniform in the direction y, perpendicular to the scanning direction. Figure 48a illustrates the difference in cross sections through a random grain structure and a synthetic structure representing an addition of sine-wave test patterns with random phase relation. The differences resulting from scanning a random grain structure or sine-wave test patterns and the suitability of N_e-values, in general, for the purpose of indicating an equivalent aperture area can be determined by a comparison with an equivalent N_o based on the *sampling* of a normalized random structure. The various equivalents N_e^*, N_e and N_o can be computed without recourse to response characteristics when the geometrical properties of the aperture are known.

The effective sampling area of an aperture (pictured as a three-dimensional body, the aperture transmittance τ representing height) may be determined by subdividing the aperture into differential columns (see Fig. 48b) with a base area $\Delta a = \Delta x \Delta y$ and constant or varying height representing the transmittance $\tau = f(x, y)$. The relative deviation obtained by taking a large number of samples from a random grain pattern with one differential column is

$$\Delta\sigma = (\tau^2 \bar{n}_o \Delta a)^{\frac{1}{2}}/\tau \bar{n}_o \Delta a$$

where $\bar{n}_o$ = average number of grains per unit area. For a normalized grain density $\bar{n}_o = 1$, the above relation becomes

$$\Delta\sigma_o = (\tau^2 \Delta a)^{\frac{1}{2}}/\tau \Delta a$$

Integration over the aperture area yields the normalized relative deviation:

$$\sigma_o = \frac{[\lim \Sigma \tau^2 \Delta a]^{\frac{1}{2}}}{\lim \Sigma \tau \Delta a} = \frac{[\int\int f^2(x, y) dx dy]^{\frac{1}{2}}}{\int\int f(x, y) dx dy} \qquad (24)$$

* The asterisk on the value N_e^* is used to indicate that this value is obtained when a random grain structure is scanned. Other values will be introduced subsequently.

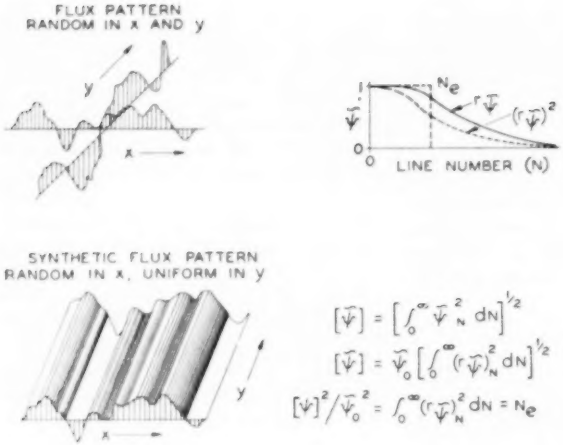


Fig. 48a. Normal and synthetic grain patterns.

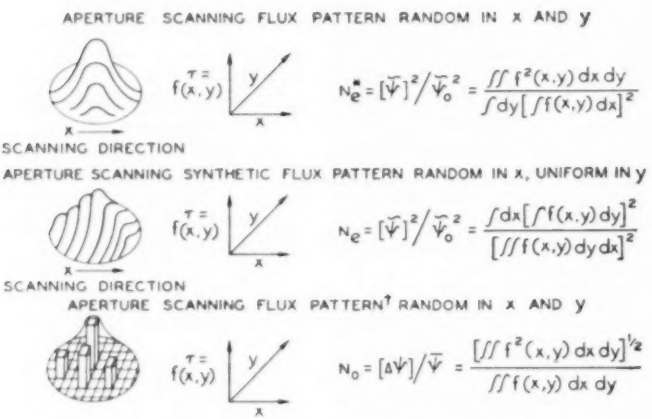

APERTURE SCANNING FLUX PATTERN RANDOM IN x AND y
$\tau = f(x,y)$
y
x
$N_e^* = [\bar{\Psi}]^2/\bar{\Psi}_0^2 = \frac{\iint f^2(x,y)\,dx\,dy}{\int dy\left[\int f(x,y)\,dx\right]^2}$
SCANNING DIRECTION
APERTURE SCANNING SYNTHETIC FLUX PATTERN RANDOM IN x, UNIFORM IN y
$\tau = f(x,y)$
y
x
$N_e = [\bar{\Psi}]^2/\bar{\Psi}_0^2 = \frac{\int dx\left[\int f(x,y)\,dy\right]^2}{\left[\iint f(x,y)\,dy\,dx\right]^2}$
SCANNING DIRECTION
APERTURE SCANNING FLUX PATTERN† RANDOM IN x AND y
$\tau = f(x,y)$
y
x
$N_0 = [\Delta\Psi]/\bar{\Psi} = \frac{\left[\iint f^2(x,y)\,dx\,dy\right]^{1/2}}{\iint f(x,y)\,dx\,dy}$
(† PATTERN FLUX NORMALIZED SO THAT $n_0 = 1$ PER UNIT AREA WITH $\bar{\tau} = 1$)

Fig. 48b. Subdivision of apertures for integration of flux values.

The normalized relative deviation σ_o has the dimension length^{-1}. The length may be regarded as the geometric mean of the sides of an equivalent rectangular sampling area a_e having constant transmittance $\tau = 1$. According to Eq. (19) the relative deviation $\sigma_o = 1/(a_e)^{\frac{1}{2}}$ can also be interpreted as the line number $\bar{N}_o$ of an equivalent square sampling aperture and Eq. (24) may, hence, be stated in the form:

$$\bar{N}_o = \frac{[\int\int f^2(x,y)dxdy]^{\frac{1}{2}}}{\int\int f(x,y)dxdy} \qquad (25)$$

The measure $\bar{N}_o$ is independent of the aperture position for both symmetric and asymmetric apertures and can, hence, be used as a standard for com-

parison. *The equivalent passband N_e^* of an aperture scanning a grain structure* random in x and y directions can be computed by subdividing the aperture into incremental sections parallel to the direction of scanning (see Fig. 48b). The mean squared flux obtained is the same as that obtained when the aperture is sampling. The flux $\Psi_{o(y)}$ at $N = 0$ contributed by each section to Ψ_o is represented by the areas $\int \tau dx$ of the sections, and because the flux is random (out of phase) in y, the total flux Ψ_o^2 is obtained by the sum of the squares $\Psi_o^2 = \Sigma[\int \tau dx]^2$. The measure N_e^* obtained when a random grain pattern is scanned is, therefore,

$$N_e^* = [\Psi]^2/\Psi_0^2 = \frac{\int\int f^2(x,y)dxdy}{\int dy[\int f(x,y)dx]^2} \tag{26}$$

The asterisk is used to distinguish N_e^* from the value N_e which will henceforth be used to indicate a sine-wave synthesis.

Evaluation of the equivalent passband N_e from a response characteristic obtained by the method of scanning sine-wave test patterns represents the case in which a synthetic structure random in the x direction but uniform (in phase) in the y direction is scanned. The aperture is subdivided into sections parallel to y. The mean-squared flux $[\Psi]^2$ is the sum of the squares of the section flux values $\Sigma[\int \tau dy]^2$, and the flux Ψ_0^2 is the squared sum of the section flux values, furnishing the ratio

$$N_e = [\Psi]^2/\Psi_0^2 = \frac{\int dx[\int f(x,y)dy]^2}{[\int\int f(x,y)dydx]^2} \tag{27}$$

All measures $\bar{N}_o$, N_e^* and N_e represent dimensionally a length^{-1}, but the formulations appear to have little resemblance to one another. Because the measures N_e^* and N_e depend on the direction of scanning, asymmetric apertures require evaluation of two N_e-values as stated by Eq. (23). For apertures having circular symmetry, however, the sampling equivalent $\bar{N}_o$ is seen to equal the geometric mean $(N_e^* N_e)^{\frac{1}{2}}$. To evaluate the relative accuracy of the three measures it is of interest to determine how closely the values computed with Eqs. (25), (26) and (27) compare in a number of representative cases. To provide N_e in relative units N_e/N_δ, the above equations must be multiplied by the ratio of the characteristic lengths δ/u when the length u chosen for computing the measure N_e differs from the length expressing a characteristic diameter of the aperture. In relative units Eqs. (25), (26) and (27) can be written:

$$\bar{N}_o/N_\delta = \frac{\delta}{u}\frac{[\int\int f^2(x,y)dxdy]^{\frac{1}{2}}}{\int\int f(x,y)dxdy} \tag{25a}$$

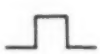
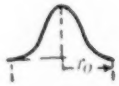
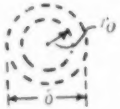
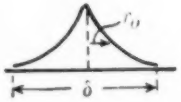
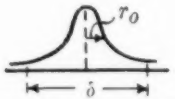
$$N_e^*/N_\delta = \frac{\delta}{u_x}\frac{\int\int f^2(x,y)dxdy}{\int dy[\int f(x,y)dx]^2} \tag{26a}$$

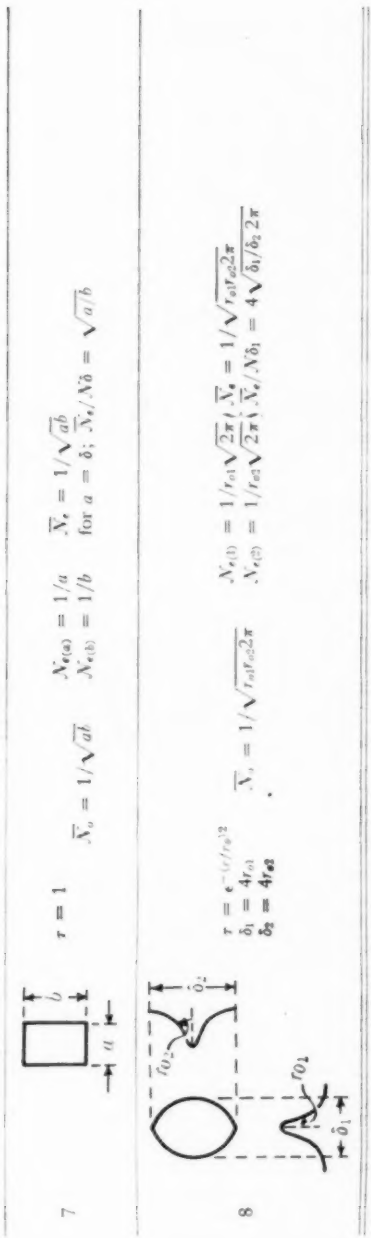
$$N_e/N_\delta = \frac{\delta}{u_x}\frac{\int dx[\int f(x,y)dy]^2}{[\int\int f(x,y)dydx]^2} \tag{27a}$$

It must be kept in mind that the length u in Eq. (25a) is the square root of an area and, therefore, independent of the aperture orientation. The length u_x in Eqs. (26a) and (27a), however, is always the characteristic aperture length in the direction x of scanning.

The measure N_e for a round aperture with $\tau = \epsilon^{-(r/r_o)^2}$, for example, may be computed in terms of a radius length $r_o = u_x$; the corresponding relative line number unit N_δ in Fig. 44 represents a length^{-1} measured by the diameter $\delta = 4r_o$. The ratio δ/u_x in this case is, therefore, four. The relative values in Table IV show that the sine-wave equivalent N_e is as good an equivalent as the value N_e^* obtained by the scanning of a random grain structure. Both values are somewhat in error for a round aperture with $\tau = 1$ and for a square scanned diagonally. Practical apertures such as lenses, grain structures or electron beams have nonuniform transmittances similar to the aperture types 4 to 6 in Table IV, for which the error is negligible or zero. The definition of N_e^* as the integral of squared response factors

Table IV. Relative Passband-Equivalents of Apertures.

No.	Aperture type		$\tau = f(x, y)$		δ	$\overline{N}_o/N\delta$	$N_e^*/N\delta$	$N_e/N\delta$
1	Square			$\tau = 1$	s	1	1	1
2	Square			$\tau = 1$	s	1	$1/(2/3)\sqrt{2} = 1.06$	$(2/3)\sqrt{2} = 0.943$
3	Round			$\tau = 1$	$2r_o$	$2/\sqrt{\pi} = 1.13$	$3\pi/8 = 1.178$	$32/3\pi^2 = 1.08$
4	Round			$\tau = \cos^2 r$	$2r_o$	1.575	1.56	1.59
5	Round			$\tau = e^{-r/r_o}$	$6r_o$	$6/e\sqrt{\pi} = 1.245$		1.245
6	Round			$\tau = e^{-(r/r_o)^2}$	$4r_o$	$4/\sqrt{2\pi} = 1.596$	1.596	1.596



given by Eq. (22) applies also to the measure N_o which is obtained from a sine-wave synthesis; i.e.,

$$N_s = {}_0f^{\infty}(\tau\psi)^2 {}_N dN \qquad (28)$$

The results obtained by a numerical integration of the squared aperture response according to Eq. (28) are illustrated by the curves $N_{s(o\rightarrow N)}$ in Figs. 41 to 46 which show the growth of the partial integral when the limit is increased from $N = 0$ towards $N = \infty$. The accurate agreement of the values obtained by this method is a check on the accuracy of the sine-wave response characteristics as well as the formulation of Eq. (27). The $\epsilon^{-\tau/\tau_o}$ aperture is of interest as a mathematical equivalent to grain structures with finite thickness. The line-number scale of this aperture is referred to a diameter $\delta = 6r_o$ which for identical values N_s places the rated resolution N_{cr} of film at the value $N_{cr}/N_\delta = 1.245/0.241 = 5.17$ of the theoretical characteristic. A comparison of Figs. 46a and 46b shows an almost perfect agreement of the sine-wave response characteristics. The resolving or sampling aperture of grain structures is, therefore, well represented† by a round aperture with a transmittance $\tau = \epsilon^{-\tau/\tau_o}$.

The value $\bar{N}_s$ of an asymmetric aperture of length a and width b can be determined accurately when the deformation of the dimensions a or b from circular symmetry does not alter the relative aperture transmittance in the b or a dimension, respectively. In this case the sine-wave measure $N_{s(a)}$ or $N_{s(b)}$ obtained with Eq. (27a) is determined by the dimension of the aperture (a or b) which is oriented parallel to the direction x of scanning, the measure being independent of the aperture scale

† A finite grain size removes the pointed tip of the aperture transmittance. The effect, however, is negligible because the flux contributed by a transmittance exceeding the value $\tau = 0.65$, ($r = 0.6\ r_o$) is only 2.5% of the total flux.

Table V. Evaluation of N_e for 40-mm Ciné Ektar Lens at f/1.6 (5°).

N/mm	$r\sqrt{}$	$\bar{a}$	$\bar{a}^2\Delta N$	$\Sigma(\bar{a})^2\Delta N$
10	0.98	0.99	9.8	
20	0.94	0.96	9.2	
30	0.90	0.92	8.5	
40	0.85	0.88	7.75	
50	0.79	0.82	6.7	41.95
60	0.74	0.765	5.85	
70	0.67	0.70	4.9	
80	0.62	0.65	4.22	
90	0.57	0.59	3.5	
100	0.53	0.55	3.0	63.42
120	0.46	0.49	4.8	
140	0.42	0.44	3.88	
160	0.39	0.40	3.2	
180	0.36	0.37	2.76	
200	0.33	0.345	2.38	80.44
250	0.27	0.30	4.5	
300	0.20	0.23	2.65	
350	0.14	0.17	1.45	
400	0.08	0.11	0.61	
450	0.03	0.05	0.13	89.78

N_e = 90 Lines/mm

Table VI. Evaluation of N_e for Grain Structures.

N/N_{cr}	$r\sqrt{}$	$\bar{a}$	$\bar{a}^2\Delta N$	$\Sigma(\bar{a})^2\Delta N$
0.05	0.97	0.985	0.049	
0.10	0.91	0.95	0.045	0.094
0.15	0.835	0.88	0.0385	
0.20	0.740	0.79	0.031	0.1635
0.25	0.67	0.685	0.0235	
0.30	0.53	0.585	0.0171	0.2041
0.35	0.44	0.50	0.0125	
0.40	0.37	0.41	0.0084	0.225
0.45	0.30	0.335	0.0055	
0.50	0.245	0.275	0.0038	0.2343
0.55	0.20	0.22	0.0024	
0.60	0.16	0.18	0.0016	0.2383
0.65	0.125	0.14	0.0010	
0.70	0.10	0.11	0.0006	0.240
0.75	0.075	0.085	0.00035	
0.80	0.058	0.065	0.0002	0.2405
0.85	0.04	0.045	0.0001	
0.90	0.03	0.04	0.0001	0.2407
0.95	0.02	0.03		
1.0	0.018	0.02		0.241

$N_e = 0.241\ N_{cr}$

factor in the y direction. The aperture is thus simply considered first as an aperture with circular symmetry and a diameter $\delta = a$, furnishing the value $N_{e(a)}$, and second as an aperture with the diameter $\delta = b$, furnishing the value $N_{e(b)}$. The geometric mean of these values (Eq. (23)) furnishes the symmetric equivalent $\overline{N}_e$. The corresponding procedure when the sine-wave response of an astigmatic lens is measured, for example, requires orientation of the sine-wave pattern and scanning direction parallel or perpendicular to the direction of astigmatism. The values $N_{e(a)}$ and $N_{e(b)}$ are then determined by numerical integration from the two corresponding sine-wave response characteristics (Eq. (28)). The evaluation of $\overline{N}_e$ is illustrated by two examples in Table IV.

The numerical evaluation of the measure N_e from a sine-wave response characteristic by means of Eq. (28) is illustrated by Table V for a 40-mm f/1.6 Ciné Ektar lens measured at f/1.6 and 5° off axis. The value $\bar{a}$ is the mean response factor within the increment ΔN. The equivalent passband N_e is obtained directly in television lines per millimeter; N_e = 90 lines/mm. Table VI illustrates the evaluation of N_e for grain structures from Fig. 46b in relative units. With reference to the rated resolving power N_{cr} of film, $N_e = 0.241\ N_{cr}$. Hence, for fine-grain positive film (Type 5302) with N_{cr} = 180 *television* lines per millimeter, N_e = 43.4 lines/mm.

4. Equivalent Aperture Diameters

The line number for known round apertures is expressed in relative units N/N_δ which refer to the aperture diameter

$$\delta = l/N_\delta$$

where l is the unit of length (l = 1 millimeter, or $l = V$ = vertical picture dimension). Relative to the equivalent passband $N_e = kN_\delta$, the diameter of these apertures is expressed by the relation $\delta = lk/N_e$ given in Table VII.

An equivalent aperture or point image of specified characteristics can thus be obtained for a system element by the

Table VII. Diameter δ and Equivalent Passband N_e of Various Aperture Types.

Aperture type	Relative transmittance	Diameter (δ)	Relation of δ to N_e
Square	$\tau = 1$	s	$s = l/N_e$
Round	$\tau = 1$	$2r_o$	$\delta_o = 1.08\, l/N_e$
Round	$\tau = \cos^2 r$	$2r_o$	$\delta_{\cos^2} = 1.59\ l/N_e$
Round	$\tau = \epsilon^{-r/r_o}$	$6r_o$	$\delta_\epsilon = 1.245\, l/N_e$
Round	$\tau = \epsilon^{-(r/r_o)^2}$	$4r_o$	$\delta_{\epsilon^2} = 1.6\, l/N_e$

insertion of its N_e-value into the relations given in Table VII.

The equivalent passband N_e (television lines) and the equivalent aperture sizes of a number of system elements used in photographic processes are summarized in Table VIII.

5. Equivalent Passband and Aperture Diameter of Processes Containing a Number of Elements in Cascade

The sine-wave response characteristic of a number of system elements in cascade, including the eye if desired, can be computed accurately by forming the products of the response factors $r_{\psi 1}\, r_{\psi 2} \ldots r_{\psi n}$ of actual response characteristics at corresponding line numbers. The equivalent passband $N_{e(p)}$ of the process is thus given accurately by the integral

$$N_{e(p)} = {}_0\!\int^{\infty} (r_{\psi 1},\, r_{\psi 2},\, \ldots\, r_{\psi n})^2 dN \quad (29)$$

Because of the nature of the response characteristics of lenses, films and television tubes it has been found that the equivalent sampling area of a combination of such "apertures" can be evaluated with usually less than 5% error by simply adding the equivalent aperture areas of the components or, as expressed in terms of equivalent aperture diameters:

$$\delta_{(p)} \simeq (\delta_1^2 + \delta_2^2 + \ldots + \delta_n^2)^{\frac{1}{2}} \quad (30a)$$

$$1/N_{e(p)} \simeq (1/N_{e_1}^2 + 1/N_{e_2}^2 + \ldots + 1/N_{e_n}^2)^{\frac{1}{2}} \quad (30b)$$

It thus becomes a simple matter to compute the equivalent passband $N_{e(p)}$ and the aperture diameter of photographic systems by the use of Eq. (30) in conjunction with Table VIII. Equation (30) is exact for exponential apertures $\tau = \epsilon^{-(r/r_o)^2}$ because the response characteristic (Fig. 44) has the form $r_{\psi(N)} = \epsilon^{-KN^2}$. The response characteristic of a system of two-dimensional apertures tends to approach this form (Fig. 44), which may therefore be used as an *equivalent response characteristic* with a line number scale $N\delta = N_e/1.6$.

The simplified method will lead to larger errors and should not be used when electrical components of a television system such as amplifiers or filters with sharp cutoff or a rising frequency characteristic are included. Although equivalent passbands (N_e) for such components have a significance, they cannot be treated as normal optical apertures. It is well known, for example, that any number of amplifier stages of limited range can be combined and corrected to have an overall "flat" response characteristic. It must also be kept in mind that the measure N_e of an optical aperture is used as a substitute for $\overline{N_o}$ and normally refers to the property of an area. N_e differs, therefore, from the "noise equivalent bandwidth" $\Delta f_{(eq)}$ of an electrical frequency-response characteristic which dimensionally refers to a length. Combinations of electrical components with two-dimensional apertures will be discussed in Part III.

Table VIII. Equivalent Passband (N_e) and Diameter (δ_o) of Equivalent Round Sampling Aperture of Imaging Components.

		N_e		δ_o (microns)	
Theoretical lens	$f/4$	287	L/mm	3.76	(See Fig. 45)
	$f/6.3$	182		5.95	
	$f/8$	143		7.52	
	$f/16$	72		15	
40-mm Ciné Ektar at	$f/1.6$ (5°)	90	L/mm	12	(Table V)
at	$f/2.8$ (5°)	180		6	
50-mm Baltar at	$f/2.8$ (5°)	64		17	(Table IX)
4-in. Super Cinephor	$f/2$	27.3		39.5	(Table IX)
Film	N_{cr}*	0.241	N_{cr}	(See Fig. 46b)	* N_{cr} = "rated" resolution at $r\downarrow \simeq 2\%$.
Plus X	110 L/mm	26.5	L/mm	40.8	
Fine-grain negative (5203)	220	53		20.4	
Fine-grain positive (5302)	180	43.4		25	
16mm reversal	150	36		30	
Square spot	$\tau = 1$	0.50	N_c**	(See Fig. 41)	** N_c = Limiting resolution at $r\downarrow = 2\%$.
Round spot	$\tau = 1$	0.45	N_c	(See Fig. 42)	
Round spot	$\tau = \cos^2 r$	0.38	N_e	(See Fig. 43)	
Exponential spot	$\tau = \epsilon^{-r/r_0}$	0.244	N_{cr}*		
Exponential spot	$\tau = \epsilon^{-(r/r_0)^2}$	0.222	N_e	(See Fig. 44)	
Theoretical lens		0.305	N_e	(See Fig. 45)	

D. GRANULARITY AND RANDOM FLUCTUATIONS IN MOTION PICTURE PROCESSES

An objective analysis of the luminance fluctuations caused by the grain structure in motion pictures requires evaluation of three factors: (1) the law of sample distribution at the source of deviations, (2) the effect of nonlinear transfer characteristics of system components on the signal-to-deviation ratio, and (3) the effect of the system apertures on the total luminance fluctuation and the sine-wave spectrum in the final image.

Subjective effects such as the appearance and threshold visibility of fluctuations (graininess) depend on the fluctuation level, gamma and aperture effect of the process of vision and can be evaluated by including the characteristics of the eye in the imaging process.

1. Deviation Characteristics of Photographic Film

The sensitometric curves of film showing the grain density D as a function of exposure E are a graph of the relative sample number as a function of exposure because

$$D \propto n/a$$

If a random distribution is assumed and $\bar{n}'$ is made equal to the average grain number (in a) at $D = 1$, the rms deviation becomes

$$[\Delta D] = (\bar{n}'D)^{\frac{1}{2}} \tag{31}$$

Density and light transmittance of the film are connected by the relation

$$D = -\log \tau$$

Differentiation of this function

$$dD/d\tau = -(\log e)/\tau = -0.4343/\tau \tag{32}$$

establishes the fact that small deviations ΔD in density or grain number cause a reciprocal deviation $\Delta\tau$ in transmittance. The relative deviation in transmittance is therefore

$$\sigma_\tau = [\Delta\tau]/\tau = 2.31[\Delta D] \tag{33}$$

and with (31)

$$\sigma_\tau = 2.31(D\bar{n}')^{\frac{1}{2}} \tag{34}$$

The effective grain number $\bar{n}'$ in actual films may, hence, be determined from measurements of σ_τ and D with

$$\left.\begin{aligned} \sigma_D &= 0.4343\,\sigma_\tau/D \\ \text{and} \\ \bar{n}' &= (2.31/\sigma_\tau)^2 D \end{aligned}\right\} \tag{35}$$

This simple relation is accurate for small deviations $\sigma_\tau < 0.1$.

Random deviations $[\Delta]_f$ caused by sources other than exposure to light, such as fog, dust and other irregularities, may superimpose a constant deviation level which remains at zero exposure. The total deviation is then increased to the value

$$[\Delta]' = ([\Delta]^2 + [\Delta]_f^2)^{\frac{1}{2}}$$

and

$$\sigma_\tau' = 2.31([\Delta D]^2 + [\Delta D]_f^2)^{\frac{1}{2}} \tag{36}$$

When both density and $[R]_\tau$ are plotted in logarithmic units (see Fig. 49) the curves showing $[R]_\tau$ as a function of density become straight lines having a slope of minus one-half for random distributions. In this case the effect of an unknown constant deviation causes at low densities a departure of measured values from a straight line. When the addition of a constant value D_f to the measured values brings the points into line, the deviations have a random distribution. The results of deviation measurements (see Appendix) made with round sampling apertures on a number of film types are shown in Figs. 49, 50, 51 and 52. The diameter δ of the sampling aperture is indicated.

Various causes introducing extraneous deviations were noted. Variations or irregularities in the transmission of the film base, thickness of the emulsion, photosensitivity, uniformity of development or physical defects introduce deviations similar to the various defects which can occur and modify the frequency distribution and consistency of

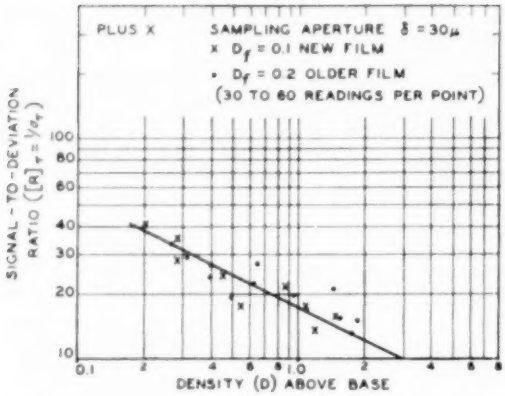


Fig. 49. Deviation characteristic of Plus X Negative Film.

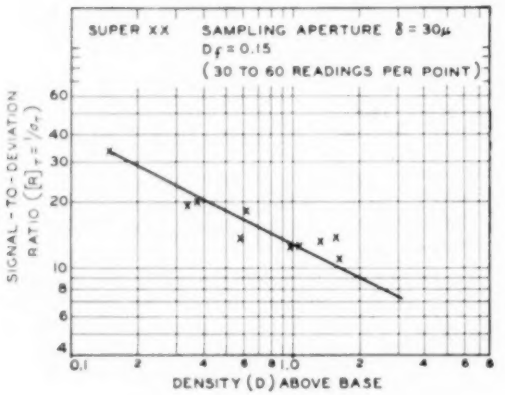


Fig. 50. Deviation characteristic of Super XX Negative Film.

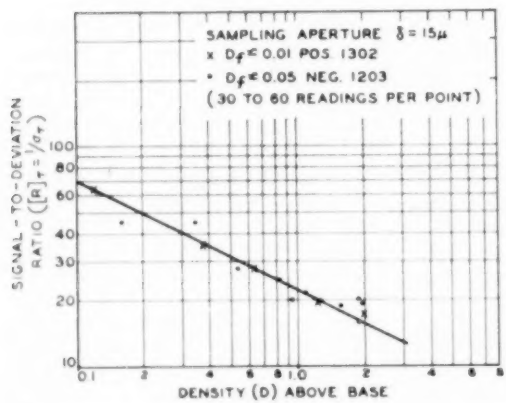


Fig. 51. Deviation characteristic of fine-grain film.

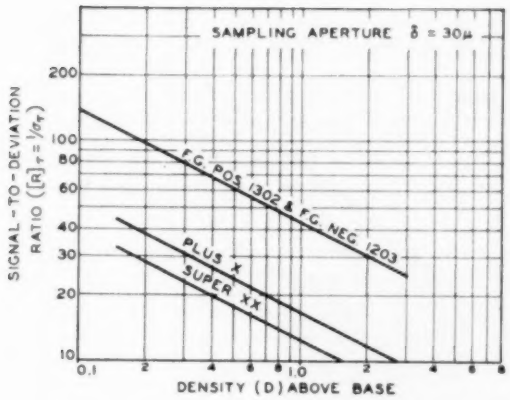


Fig. 52. Deviation characteristics of several film types.

electrical fluctuations in television systems. In comparison with the immense number of samples involved in a dynamic measurement of electrical fluctuations it can be expected that static sample measurements on a small film area will show a greater spread of values.

The measured characteristics (Figs. 49, 50 and 51) substantiate the variation of $[R]_\tau$ with the one-half power of the grain density predicted by Eq. (34) for a random distribution. Additional proofs can be obtained directly from any one set of sample readings taken to determine a point on the $[R]_\tau$ characteristics. When the readings are plotted on probability paper (arranged in order according to value), a gaussian distribution of values is indicated by a grouping around a straight line. Figure 53 shows the distribution of readings determining three points on the $[R]_\tau$ characteristic of Plus X film and one point on the characteristic of fine-grain positive film.

These plots may be compared with Fig. 54 which shows two sets of sample readings taken on photographs of electrically produced "grain" structures in a single television frame. The photographs were made on 4 × 5 in. film, a positive of which was sampled with a round aperture. The electrical fluctuations so recorded are random fluctuations occurring in the current of a multiplier phototube exposed to a "d-c" light source and passed through electrical amplifiers having a constant or a rising (peaked) frequency response characteristic. The agreement with the theory is sufficiently good to justify the assumption that the *deviations in motion picture film are substantially gaussian* and certainly random as defined in Sec. C1.

A comparison of deviation ratios in film types is made on the basis of sampling apertures having equal areas or equivalent optical passbands. For a random distribution of samples, the deviation ratio $[R]_\tau$ is proportional to the diameter δ of a round sampling aperture. The curve for fine-grain film in Fig. 52 is, therefore, obtained from Fig. 51 by multiplying the $[R]_\tau$-scale by the ratio of the aperture diameters. The validity of this process can be demonstrated visually by photomicrographs of equal densities on Plus X and 1302 positive film. For equal magnification the grain structures are shown by the prints 0 and 1a in Fig. 55. Magnifications in the ratio of their $[R]$-values results in equal deviations per unit area in the prints 1 and 1a. Out-of-focus projections are a convenient means for reducing the optical passband and thus visually checking the relative "frequency" distribution of the devia-

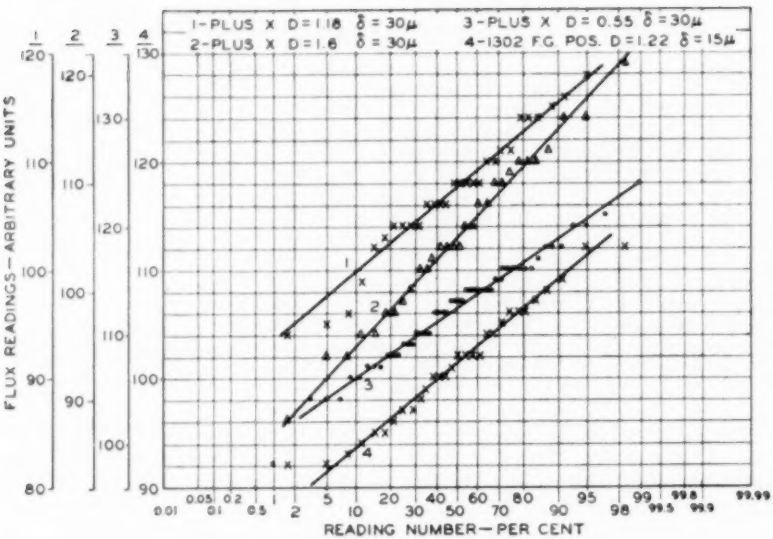


Fig. 53. Sample readings on Plus X and fine-grain films plotted on probability paper.

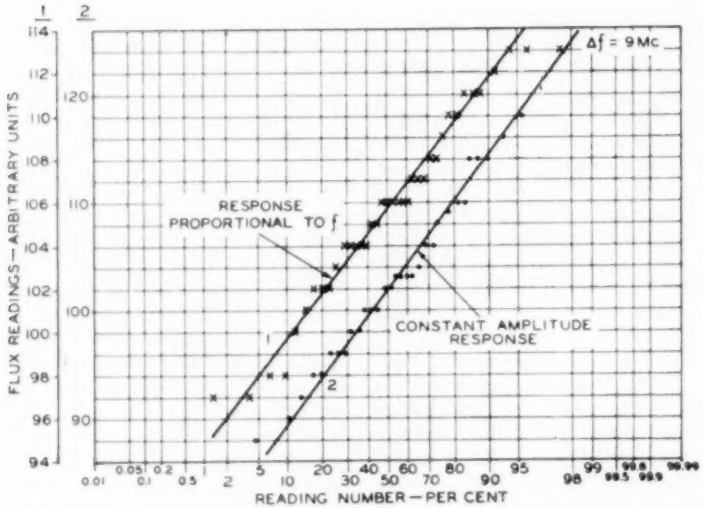


Fig. 54. Sample readings of television "noise" photographed on 4×5 in. film plotted on probability paper.

Fig. 55. Comparison of grain structures in photographic film after integration by aperture processes.

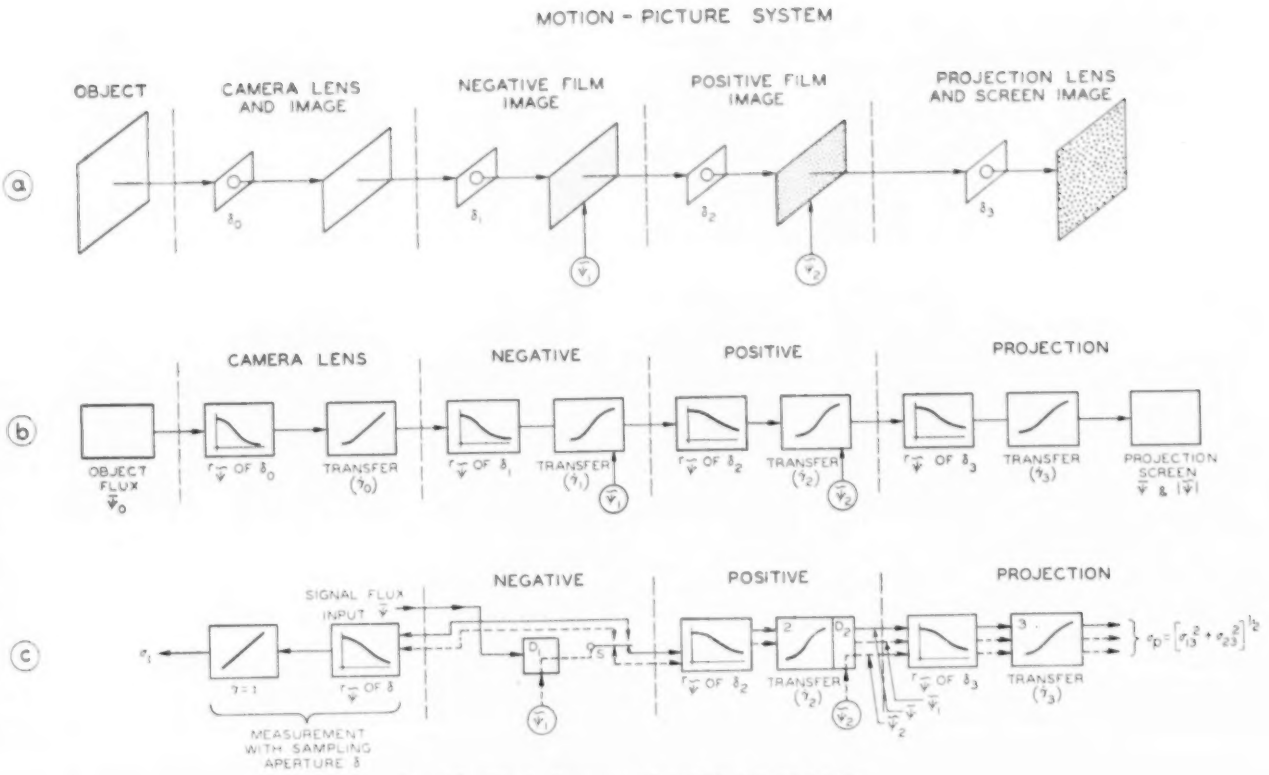


Fig. 56. Block diagrams of motion picture system.

tions, because the optical passband decreases in proportion to the diameter of the disc of diffusion (sampling aperture) in the out-of-focus projection. The integrated grain structures 2, 2a, 3, 3a, etc., of the two film types have a substantially identical appearance for passbands in the ratio of their $[R]$-values, confirming a substantially identical distribution. The size of the integrating aperture of the projection is shown by pinhole images under the grain images. The aperture sizes are indicated in microns (μ).

2. Sampling Apertures and Transfer of Deviations in Motion Picture Systems

The four dominant sampling apertures and intermediate images of a motion picture system are shown in Fig. 56a. The corresponding aperture response characteristics $r_\psi = f(N)$ of the system elements, their transfer characteristics $\psi_{out} = f(\psi_{in})$ and the points where random deviations (σ) are introduced into the system are indicated in Fig. 56b. It is assumed that no aperture effects are introduced by camera, printing and projector mechanisms.

A number of minor apertures have been omitted in this diagram because they are of much smaller magnitude than the main sampling apertures of the system. The *developed* grain structures of the negative and positive films, for example, introduce a small aperture effect in printing and projection processes in addition to their main aperture effect which occurs during exposure in the undeveloped grain structure. The diffusion of light is, consequently, the aperture effect of the black silver grain structure of the developed films, however, is of much smaller magnitude than in the undeveloped transparent state of the structure and can be neglected.

For an analysis of deviations the block diagram contains, therefore, only the elements shown in Fig. 56c indicating the dependence of the relative deviations σ_1 and σ_2 on the densities D_1 and D_2 of the respective film processes. The method of measuring the relative deviation (σ_1) in the negative film with a known sampling aperture (δ) is indicated by an alternate path of ψ_1 over the switch S.

The value of the relative deviation has been determined by measurement for several motion picture film types with the use of a round sampling aperture of specified diameter δ. In the actual process (Fig. 56c), the deviation flux ψ_1 from the negative is "filtered" by the response characteristics of the apertures δ_2 and δ_3 and passed through the transfer characteristics 2 and 3 to the projection screen. The sampling aperture δ used in the measurement of σ_1 is, hence, replaced by the cascaded value $\delta_{23} = (\delta_2^2 + \delta_3^2)^{\frac{1}{2}}$. According to Eq. (17) the deviation is changed in inverse proportion with the aperture diameter; it is further changed by the transfer ratios g/G,† i.e., the point gammas γ_2 and γ_3 of the two transfer characteristics. The relative deviation σ_1 from the negative is, therefore, changed after transfer to the projection screen to the value

$$\sigma_{13} = 1/[R]_{13} = \sigma_1(\delta/\delta_{23})\gamma_2\gamma_3 \quad (37a)$$

Similarly deviations originating in the positive film are changed from the measured value σ_2 to the value

$$\sigma_{23} = 1/[R]_{23} = \sigma_2(\delta/\delta_3)\gamma_3 \quad (37b)$$

The total relative deviation σ_p at the projection screen is then obtained by a quadrature addition of the relative deviations σ_{13} and σ_{23} as illustrated by numerical examples in the following section.

3. The Signal-to-Deviation Ratio in Projected Positive Film

The signal-to-deviation ratio $[R]_p$ in a standard 35mm motion picture process is determined by the following

† See Part I, p. 145.

components: Plus X negative film, 1302 fine-grain positive film, and a 4-in. $f/2$ Super Cinephor projection lens. *The sampling aperture δ_{23} for deviations originating in the negative film* is the cascaded value of the equivalent aperture of the positive film ($\delta_2 = 25\mu$) and the equivalent aperture of the Super Cinephor projection lens ($\delta_3 = 39.5\mu$)

$$\delta_{23} = (25^2 + 39.5^2)^{\frac{1}{2}} = 46.7\ \mu$$

A second value

$$\delta'_{23} = (25^2 + 30^2)^{\frac{1}{2}} = 39\ \mu$$

representing a combination of the positive film and a physical 30-μ aperture will be used for test purposes. A tabulation of the response factors of motion picture components and combinations (products) is given in Table IX. (Note the close agreement of the equivalent apertures computed from the actual response characteristics with those obtained above.)

Representative transfer characteristics of the negative and positive films are shown in Figs. 14 and 15 of Part I. The total density values D_1 and D_2, the densities above base D_1^* and D_2^*, and the point gamma of the positive film (γ_2) are listed in Table X.

A projection lens having a linear transfer characteristic with a constant gamma of unity ($\gamma_3 = 1$) requires a complete absence of lens flare and a totally dark and nonreflecting projection room. In all practical cases lens flare and ambient light superimpose a light flux "bias" $\mathcal{J}_0$ on the projection screen. The signal flux is, hence, increased by the ratio $(\mathcal{J} + \mathcal{J}_0)/\mathcal{J}$ which, as easily shown, reduces the constant value $\gamma_3 = 1$ as a function of $\mathcal{J}$ to the values $\gamma_3 = \mathcal{J}_3/(\mathcal{J}_3 + \mathcal{J}_0)$. Expressed in units of film transmittance

$$\gamma_3 = \tau_2/(\tau_2 + \tau_b) \qquad (38)$$

For a normal high light transmittance $\tau_{2max} = 0.5$, a 1.5% light bias $\mathcal{J}_0 = 0.015\ \mathcal{J}_{3max}$ (compare Fig. 18, Part I) corresponds to the value $\tau_b = 0.015 \times \tau_{2max} = 0.0075$ and $\gamma_3 = \tau_2/(\tau_2 + 0.0075)$ which is listed in the lower portion of Table X for various values of D_0 and $\tau_2 + 0.0075$, the latter being proportional to the total screen luminance $B + B_0$. The effect of the light bias is computed separately by first letting γ_3 equal unity. The ratio $[R]_1$ of the Plus X negative film measured with $\delta = 30\mu$ is taken from Fig. 52. The transferred values $[R]^*_{13}$, indicated by an asterisk, are computed with Eq. (37a) for the cascaded sampling apertures.

Table IX. Sine-Wave Response Factors of Motion Picture Components.

N/mm	Baltar at $f/2.8$	Neg. film Plus X	Fine-grain pos. 5203	Cinephor at $f/2$	Aperture 30 μ	3 + 4	3 + 5	1 to 4
10	0.99	0.93	0.97	0.94	0.97	0.91	0.94	0.84
20	0.95	0.78	0.90	0.80	0.91	0.72	0.82	0.54
30	0.90	0.60	0.815	0.60	0.80	0.49	0.652	0.26
40	0.82	0.43	0.70	0.45	0.66	0.315	0.462	0.111
50	0.74	0.30	0.59	0.33	0.51	0.195	0.30	0.044
60	0.66	0.205	0.48	0.25	0.35	0.12	0.168	0.016
70	0.58	0.14	0.39	0.18	0.22	0.07	0.084	0.006
80	0.50	0.09	0.31	0.13	0.09	0.04	0.028	
90	0.45	0.07	0.25	0.10	0	0.025		
100	0.40	0.03	0.20	0.08		0.016		
No.	1	2	3	4	5	3 + 4	3 + 5	1 to 4
N_c/mm	64	26.5	43.4	27.3	36	23.5	27.8	15.8
$\delta_{c\mu}$	17	40.8	25	39.5	30	46	39	68
			Computed with Eq. (30): $\delta_{\mu_{23}}$ =			46.7	39	64.5

Table X. Signal-to-Deviation Ratios for Plus X Negative Film Copied on 5302 Fine-Grain Positive Film and Sampled by an Aperture

Sampling aperture					δ	δ_{23}	δ_{23}	δ_3	δ_3	δ_{23} & δ_3	δ_{23} & δ_2
Microns					30	39	46.7	30	39.5	39 & 30	46.7 & 39.5
D_1	D_2	D_1*	D_2*	γ_2	$[R]_1$	$[R]^*_{13}$	$[R]^*_{13}$	$[R]^*_{23}$	$[R]^*_{23}$	$[R]^*_p$	$[R]^*_p$
0.36	2.77	0.2	2.72	1.66	38	30	35.8	26	34.2	19.6	24.7
0.64	2.3	0.48	2.25	1.85	25	17.5	21	29	38.2	15	18.5
0.75	2.1	0.59	2.05	1.95	22	14.6	17.5	30.5	40.2	13.1	16
0.88	1.9	0.73	1.85	2.0	20	13.0	15.6	32	42	12.1	14.6
1.0	1.6	0.84	1.55	2.0	18.5	12.0	14.4	35	46.1	11.3	13.7
1.13	1.35	0.97	1.3	1.88	17.5	12.1	14.5	38	50	11.5	13.8
1.37	0.91	1.21	0.86	1.57	15.5	12.8	15.3	47	62	12.35	14.9
1.6	0.6	1.44	0.55	1.21	14.5	15.6	18.7	59	78	15.1	18.2
1.79	0.4	1.63	0.35	0.9	13.2	19.1	23	74	97.5	18.75	22.3
1.95	0.27	1.79	0.22	0.64	12.8	26.0	31.2	93	122	25	30.2
2.1	0.19	1.94	0.14	0.4	12.3	40	48.0	118	155	38	46.0
		$\tau_2 + 0.0075$	D_2	γ_3	$[R]_p$		γ_{13}/γ_{23}	γ_p/γ_{23}	δ_{po}	$N_{e(p)}$	
(Sampling aperture: – δ_{23} & δ_3; microns, 46.7 & 39.5)		0.009	2.77	0.227	109		1.04	1.44	42.6	25.4	
		0.0125	2.3	0.4	46.3		1.97	2.21	45.5	24	
		0.016	2.1	0.515	31		2.5	2.69	45.5	24	
		0.020	1.9	0.63	23.2		2.92	3.08	45	24	
		0.033	1.6	0.77	17.8		3.48	3.62	45.9	23.6	
		0.052	1.35	0.86	16		3.75	3.87	45	24	
		0.13	0.91	0.94	15.9		4.4	4.5	46.3	23.6	
		0.258	0.6	0.97	18.8		4.53	4.65	46.6	22.1	
		0.405	0.4	0.98	22.8		4.6	4.71	46	22.6	
		0.544	0.27	0.985	30.7		4.25	4.36	46.1	23.5	
		0.652	0.19	0.99	46.5		3.52	3.66	46.5	23.2	
				Eq. (38) $\tau_b = 0.0075$			Eq. (42)	Eq. (43)	Eq. (45)		

Note: The values $[R]^*$ are computed for zero lens flare and zero ambient light ($\tau_b = 0$, $\gamma_3 = 1$)

$\delta'_{22} = 39\mu$ and $\delta_{23} = 46.7\mu$ letting γ_3 equal unity. The signal-to-deviation ratios $[R]^*_{23}$ of the positive film alone are tabulated likewise for the density values D_2^* (from Fig. 52) and the sampling apertures $\delta'_3 = 30\mu$ and $\delta_3 = 39.5\mu$ (cinephor lens). The total signal-to-deviation ratio $[R]^*_p$ in the projection is then computed with

$$1/[R]^*_p = (1/[R]^*_{12}{}^2 + 1/[R]^*_{23}{}^2)^{\frac{1}{2}} \quad (39)$$

Division of the values $[R]^*_p$ by corresponding values γ_3 furnishes the values $[R]_p$ containing the effect of the light bias J_0.

A comparison of the values $[R]^*_{12}$ from the negative alone with the values $[R]^*_p$ of the process shows that the fine grain of the positive film contributes little to the total deviation. As illustrated by the block diagram Fig. 56c, the total deviation is a composite value of deviations from two unequal passbands and requires further discussion.

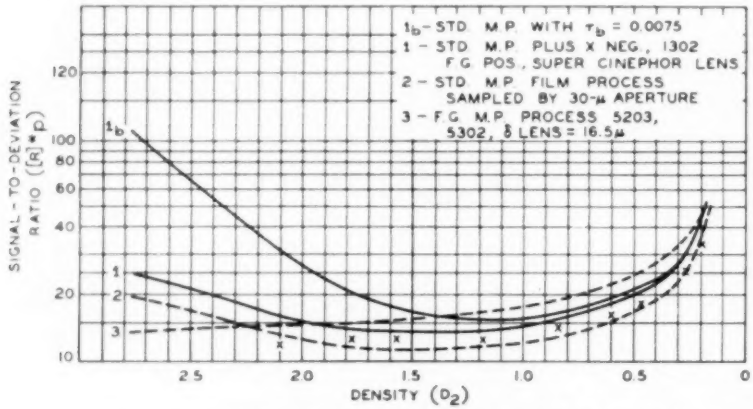


Fig. 57a. Deviation characteristic of projected motion picture without ambient light.

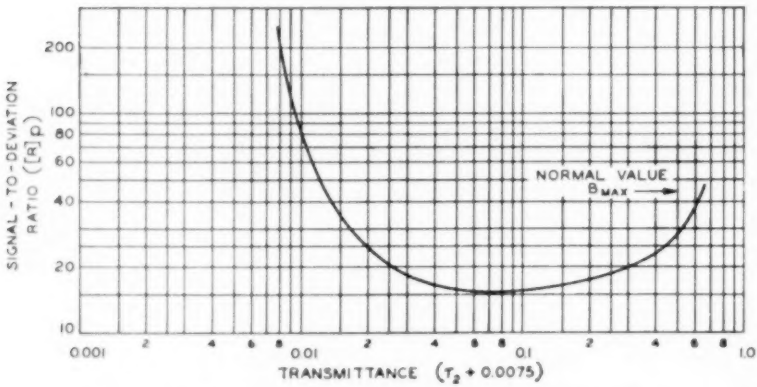


Fig. 57b. Deviation characteristic of projected motion picture with ambient light.

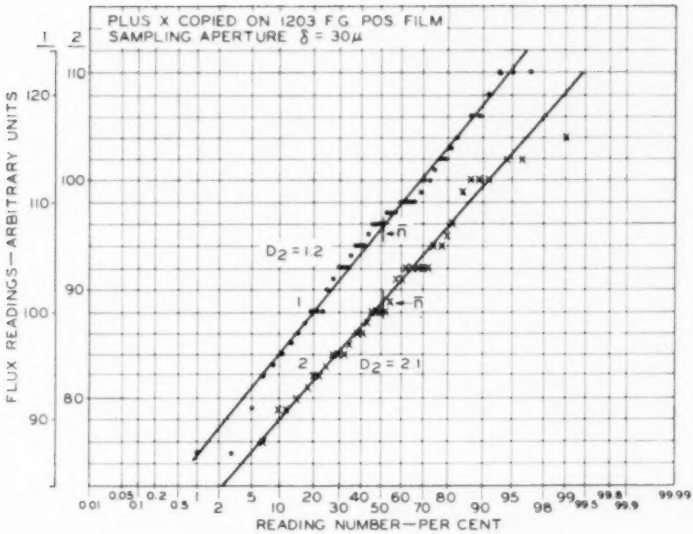

PLUS X COPIED ON 1203 F.G. POS. FILM
SAMPLING APERTURE δ = 30μ
FLUX READINGS—ARBITRARY UNITS
READING NUMBER—PER CENT
D2 = 1.2
D2 = 2.1

Fig. 58. Sample readings on motion picture positives plotted on probability paper.

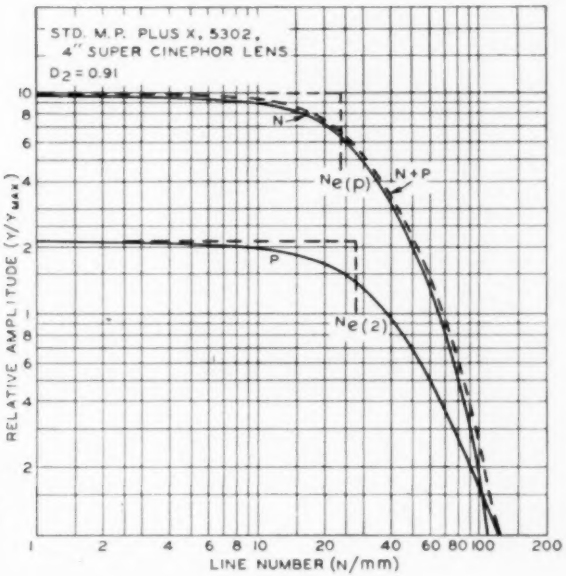


Fig. 59. Sine-wave spectrum of deviations in motion picture process.

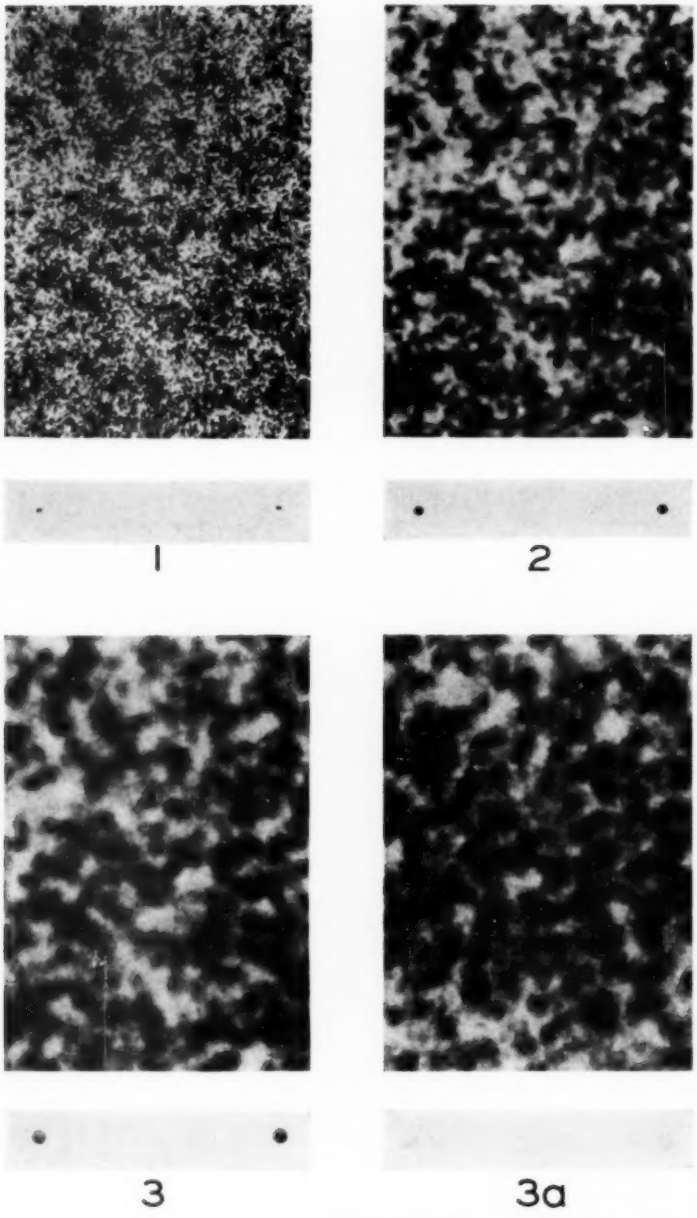


Fig. 60. Composite grain structures in motion picture positives.

A plot of the signal-to-deviation ratios $[R]^*_p$ and $[R]_p$ from Table X is shown in Figs. 57a and 57b, illustrating the considerable reduction of deviations and corresponding improvement of $[R]_p$ in the shadow tones by ambient light. The broken line, curve 2 in Fig. 57a, for a 30-μ aperture was computed for comparison with a direct measurement. The measured values (x) were obtained by sampling a contact print (on 5302 stock) of a IIB sensitometer exposure on Plus X film with a 30-μ aperture (spray process on negative, deep tank on positive by De Luxe Laboratories). The agreement with computed values is good, particularly when it is considered that optical effects and film slippage in printing cause additional integration and increase the sampling aperture and $[R]^*$-values. Figure 58 shows that the gaussian distribution is maintained in the composite structure sampled by a 30-μ aperture.

4. The Optical Passband of the Total Deviation in Projected Positive Film

The sine-wave components of different passbands are combined into a single passband by a geometric addition of like sine-wave components. To perform this addition the relative values of corresponding Fourier components must be known. The flux Ψ_0 representing the flux or amplitude Y_o of the Fourier component approaching zero line number is obtained from Eqs. (27) and (20) $\Psi_0 = \bar{\Psi}\sigma/N_s^{\frac{1}{2}}$. Substitution of $1/N_s = c^2\delta$ from Table VII yields

$$Y_o = c\bar{\Psi}\delta^{\frac{1}{2}}\sigma = c\bar{\Psi}\delta^{\frac{1}{2}}/[R] \qquad (40)$$

in which c is a numerical constant.

Because the relative deviation (σ) itself is proportional to $1/\delta$ and $\bar{\Psi}$ is proportional to δ^2, Eq. (40) reveals the interesting fact that the amplitude of the zero-line number component (Y_o) or (Ψ_o) increases with the 3/2 power of the diameter of the sampling aperture; a fact having no parallel in electrical filter circuits. The amplitudes of the zero line number components in the projected relative deviation $\sigma_{13} = 1/[R]_{13}$ originating in the negative, and the projected relative deviation $\sigma_{23} = 1/[R]_{23}$ originating in the positive follow from Eq. (40).

$$\begin{aligned} Y_{13} &= c\bar{\Psi}_3\delta_{23}^{\frac{1}{2}}/[R]_{13} \\ Y_{23} &= c\bar{\Psi}_3\delta_2^{\frac{1}{2}}/[R]_{23} \end{aligned} \qquad (41)$$

and their ratio is:

$$Y_{13}/Y_{23} = (\delta_{23}/\delta_2)^{\frac{1}{2}}([R]_{23}/[R]_{13}) \quad (42)\dagger$$

The constants c and the signal flux ratio cancel out because they refer to the common signal flux from the projection lens (see Fig. 56). The geometric sum $Y_p = (Y_{13}^2 + Y_{23}^2)^{\frac{1}{2}}$ can be expressed by the ratio

$$Y_p/Y_{23} = \left[\left(\frac{Y_{13}}{Y_{23}}\right)^2 + 1\right]^{\frac{1}{2}} \quad (43)\dagger$$

Analogous to Eq. (41), Y_p can also be expressed by

$$Y_p = c\bar{\Psi}_p\delta_p^{\frac{1}{2}}/[R]_p \qquad (44)$$

Forming the ratio Y_p/Y_{23} with Eqs. (44) and (41) eliminates the constants c and the identical flux values $\bar{\Psi}_p = \bar{\Psi}_3$, and yields an expression for *the equivalent sampling aperture* δ_{po} *for the total relative deviation* in known quantities:

$$\delta_{p_o} = \left[\frac{[R]_p}{[R]_{23}}\frac{Y_p}{Y_{23}}\right]^2\delta_3 \qquad (45)\dagger$$

The corresponding equivalent passband is: $N_{s(p)} = 1.08/\delta_{po}$. The amplitude ratios and the equivalent aperture of the standard motion picture process are listed in Table X. In photographic processes the values N or N_s are usually measured in lines per millimeter whereas lengths or aperture diameters (δ) are measured in microns. A conversion factor of 10^3 appears, therefore, in the quantities in Table X.

It is seen from Table X that the relative amplitudes and equivalent passbands vary somewhat with the film

† The $[R]$ values in these equations may be replaced by the corresponding $[R]^*$ values computed for $\gamma_3 = 1$ which cancels out in these ratios.

density. A set of conditions is shown in Fig. 59 for $D_2 = 0.91$. The amplitude characteristic of the deviations from the negative film (curve N) is given by the combination of 3 + 4 in Table IX. The relative amplitude scale is indicated by the value $\gamma_{13} = (4.4/4.5)\ \gamma_p$ at $N = 0$. The response characteristic (P) for the deviation from the positive film is determined by the projection lens and copied from column 4 of Table IX. Its initial amplitude is $\gamma_{23} = \gamma_p/4.5$. The geometric addition $N + P$ of the composite deviations from both films shows the negligible effect of the fine-grain positive on the total deviation at the density $D = 0.91$. The aperture effect of the positive film can be demonstrated visually by photomicrographs of the grain structure in 5302 positive film containing a print of the grain structure of Plus X negative film. Print 1 of Fig. 60 is a sharp copy of the composite grain structure. The large white patches represent integrated grains from the negative film which average in diameter the equivalent resolving aperture ($\delta_2 = 25\mu$) of the positive film. Prints 2 and 3 are out-of-focus projections with lens apertures $\delta_3 = 5\mu$ and $\delta_3 = 10\mu$, respectively, demonstrating the integration of the fine-grain structure of the positive film by an excellent projection lens. The negative grain in print 3 is, hence, integrated by an equivalent aperture of 27-μ diameter (Eq. (30)) while the positive grain is integrated by a 10-μ aperture. A composite print 3a was made from a positive copy of the negative plate projected with the equivalent aperture $\delta_{13} = 26.6\mu$ and the fine-grain positive placed over and spaced from the copy of the negative so that it was projected simultaneously with an equivalent aperture $\delta_3 = 13\mu$ to approximate artificially the conditions of print 3. The similarity of the grain structures in prints 3 and 3a is apparent.

The use of positive film with a resolving power and grain structure equal to that of the negative film has a more noticeable effect on the total deviation in the projected positive print. Table XI was computed for the same relations of densities and gammas as listed in Table X, but the Plus X film was replaced by 5203 fine-grain negative film and a better projection lens was used. This combination of two fine-grain films represents a condition used for television recording on 16mm film. The signal-to-deviation ratios $[R]^*_p$ computed for a projection lens with an equivalent aperture $\delta_3 = 16.5\mu$ are only slightly better in the highlight range (see curve 3 in Fig.

Table XI. Signal-to-Deviation Ratios for 5203 Fine-Grain Negative Film Copied on 5302 Fine-Grain Positive Film and Sampled by a 16.5-Micron Aperture ($\gamma_3 = 1$).

$\delta =$	30μ	30μ*	16.5μ	30 & 16.5μ				
D_2	$[R]_1$	$[R]^*_{13}$	$[R]^*_{23}$	$[R]^*_p$	γ_{13}/γ_{23}	γ_p/γ_{23}	$\delta_{p_0(\mu)}$	$N_{e(p)}$
2.77	100	60	14.3	13.9	0.32	1.05	17.2	63
2.3	62	33.5	16	14.4	0.645	1.19	18.8	57.5
2.1	58	30	16.8	14.7	0.77	1.26	20	54
1.9	52	26	17.6	14.5	0.91	1.35	20.3	53.2
1.6	48	24	19.3	15	1.09	1.48	21.8	49.5
1.35	44.4	23.5	20.9	15.6	1.2	1.56	22.5	48
0.91	40	25.5	25.8	18.2	1.365	1.69	23.4	46.2
0.6	36.6	30	32.5	22.0	1.46	1.77	23.8	45.5
0.4	34	38	40.6	27.8	1.44	1.75	23.5	46
0.27	32.4	51	51.0	35.4	1.35	1.68	22.5	48
0.19	32	80	65	50.6	1.1	1.48	22	49

* Negative sampled by $\delta_2 = 25\mu$ in cascade with $\delta_3 = 16.5\mu$, equalling $\delta_{23} = 30\mu$.

57a) because they refer to a higher equivalent passband $N_{e(p)}$.† Amplitude distribution and equivalent passbands are shown in Fig. 61. It is pointed out that this comparison is made on the basis of *unit areas* and does not refer to actual frame sizes!

A reduction print of a 35mm Plus X negative on 16mm 5302 positive film has substantially the same relative deviation per unit area as the above fine-grain process. The number of grains per *unit* area in the reduced negative image is increased by the ratio of the frame areas, and $[R]^*_{13}$ increases, therefore, by the linear reduction factor 15.7/7 = 2.25. In comparison, the change from Plus X to 5203 fine-grain negative film increases $[R]_{13}$ 2.6 times (see Fig. 52). In the reduction print the sampling aperture of the negative film, however, is increased by the printer lens which reduces the passband and decreases the difference in $[R]$-values.

The effect of the quality of the projection lens on the total relative deviation is readily computed by the above method and is illustrated in Fig. 62 for three values of the sampling aperture δ_3 of the lens. When δ_3 is large compared to the effective aperture δ_2 of the positive film, the deviations from the negative film are predominant ($[R]_{13} \ll [R]_{23}$). When the lens quality is increased ($\delta_3 < \delta_2$) the deviations ($1/[R]_{23}$) from the positive film increase because of the increased passband and exceed the deviations from the negative film which approach a fixed value determined by the passband of δ_2. The relative amplitudes and line number spectra of $\mathcal{V}_{13}$ and $\mathcal{V}_{23}$ for $D_2 = 0.91$ are approximated by exponential aperture characteristics (Fig. 44, Part I).†

5. Signal-to-Deviation Ratios and Gamma of Motion Picture Film for Television Recording

Television images are recorded on film for the purpose of storing video signals for use at a later time. To obtain a perfect duplicate of the original signals, the overall transfer characteristic of the system components involved in

† It is cautioned that equal $[R]_p$-values do not necessarily indicate equal visibility of the grain structure.

† The line number scale is established with Eq. (19) and Table VII.

$$N\delta_{ex} = N_e/1.6$$

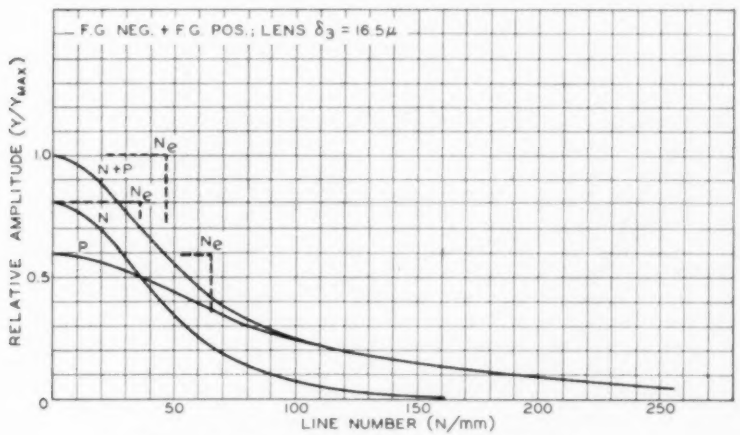


Fig. 61. Sine-wave spectrum of deviations in fine-grain motion picture process.

the recording and reproducing process from signal to duplicate signal must be linear. This requirement implies that the product of the point gammas of the system components must equal unity at any signal level as stated by

$$(\gamma_{v_1}\gamma_{k_1})(\gamma_1\gamma_2)(\gamma_c\gamma_{v_2}) = 1 \qquad (46)$$

The first product contains the gammas of video amplifier (γ_{v1}) and associated recording kinescope (γ_{k1}), the second term contains the gammas of the negative and positive films used in the photographic process (neglecting lens flare), and the third term contains the gammas of the reproducing camera tube (γ_c) and its associated video and correction amplifier (γ_{v2}). The combination of a television process of constant overall gamma with a motion picture process of constant overall gamma has many advantages as pointed out in Part I.

The overall transfer characteristic of the motion picture process most suitable for video recording has a constant gamma ($\gamma_1\gamma_2$) and a relatively short density range ΔD_2 (see Table III, Part I). It is of interest to determine the effects of varying gamma and density range of the negative film on the signal-to-deviation ratio $[R]_p$, when the product $\gamma_1\gamma_2$, the exposure range of the negative, and consequently the density range ΔD_2 in the positive film are maintained constant. To prevent distortion, it is required to operate on film characteristics having adequately long constant-gamma sections. For a numerical evaluation, the values given in Fig. 52 for fine grain 5203 and 5302 film will be assumed.

Given an exposure range $\Delta \log E_1 = 1.3$ of the negative and a density range $\Delta D_2 = 1$ in the positive, the product of the film gammas must have the value $\gamma_1\gamma_2 = 1/1.3$, which can be obtained, for example, with the values $\gamma_1 = 0.77$, $\gamma_2 = 1$, or $\gamma_1 = 1.54$, $\gamma_2 = 0.5$. Densities and signal-to-deviation ratios for these two conditions are listed in Table XII. The signal-to-deviation ratios $[R]^*_{23}$ of the positive film remain the same for both conditions because they are determined by the fixed density range ΔD_2. The values $[R]^*_{13}$ transferred from the negative to the positive, however, change in proportion to $1/\gamma_2$ and as the square root of the negative

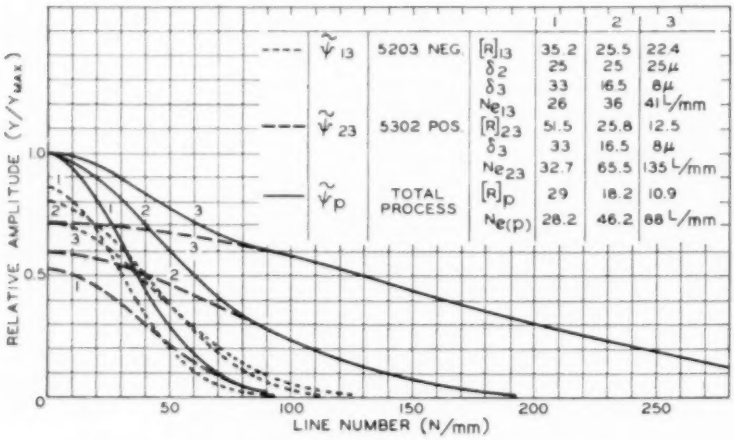


Fig. 62. Effect of projection lens quality on sine-wave spectrum of deviations in fine-grain motion picture process.

Table XII. Signal-to-Deviation Ratios for Constant-Gamma Films (Fine-Grain 5203 and 5302) With Good Lens ($\delta_3 = 19\mu$, $\gamma_3 = 1$).

			δ (microns):		30	30	19	30 & 19					30	19	30 & 19
Log E_1	D_1*	Log E_2	γ_2	D_2*	$[R]_1$	$[R]^*_{13}$	$[R]^*_{23}$	$[R]^*_p$	D_1*	D_2*	γ_2		$[R]^*_{13}$	$[R]^*_{23}$	$[R]^*_p$
0	0.25	1.25	2	2.25	87.5	43.7	18.6	17.1	0.25	2.25	1		87.5	18.6	18.2
	0.50	1.0	2	1.75	62	31	21.2	17.5	0.75	1.75	1		50	21.2	19.6
	0.75	0.75	2	1.25	50	25	25	17.7	1.25	1.25	1		39	25	21
	1.0	0.5	2	0.75	44	22	32	18.1	1.75	0.75	1		33	32	23
1.3	1.25	0.25	2	0.25	39	19.5	56	18.4	2.25	0.25	1		29	56	25.8
	($\gamma_1 = 0.77$)			$\Delta D_2 = 2$					($\gamma_1 = 1.54$) $\Delta D_2 = 2$						

	δ (microns):		30	30	19	30 & 19					30	19	30 & 19
Log E_1	D_1*	D_2*	γ_2	$[R]_1$	$[R]^*_{13}$	$[R]^*_{23}$	$[R]^*_p$	D_1*	D_2*	γ_2	$[R]^*_{13}$	$[R]^*_{23}$	$[R]^*_p$
0	0.25	1.25	1	87.5	87.5	25	24	0.25	1.25	0.5	175	25	24.8
	0.50	1.0	1	62	62	27.8	25.3	0.75	1.0	0.5	100	27.8	26.8
	0.75	0.75	1	50	50	32	27	1.25	0.75	0.5	78	32	29.6
	1.0	0.5	1	44	44	39	29.1	1.75	0.5	0.5	66	39	33.5
1.3	1.25	0.25	1	39	39	56	32	2.25	0.25	0.5	58	56	40.4
	($\gamma_1 = 0.77$) $\Delta D_2 = 1$							($\gamma_1 = 1.54$) $\Delta D_2 = 1$					

density $D_1{}^*$. The values $[R]^*_{12}$ and $[R]^*_p$ increase, therefore, when the *negative gamma* increases. This relation is equally true for other values of the density range $\Delta D_2{}^*$ in the positive print as shown by Table XII and the graphs in Fig. 63 for $\Delta D_2 = 2$ for two conditions $\gamma_1 = 0.77$, $\gamma_2 = 2$, and $\gamma_1 = 1.54$, $\gamma_2 = 1$. The contribution by the positive film deviations becomes relatively larger when the negative gamma is increased, and the curve of $[R]^*_p$ for the process cannot improve beyond the limit set by $[R]^*_{23}$. After conversion into video signals the signal-to-deviation ratios $[R]^*_p$ of the photographic process are modified by the gamma of the television camera chain to the value

$$[R]^*_p{}' = [R]^*_p/(\dot{\gamma}_c\dot{\gamma}_{r_p}) \qquad (47a)$$

It is emphasized that this expression does not take into account the aperture effects of television components and is, therefore, not an electrical signal-to-noise ratio. For a given camera chain, however, the values $[R]^*_p{}'$ have a direct relation to the electrical fluctuation signals caused by the photographic process and Eq. (47a) can, hence, be used to indicate the relative performance of the photographic link in the recording system. According to Eq. (46) the product $1/(\dot{\gamma}_c\dot{\gamma}_{r_p})$ may be replaced by $K(\dot{\gamma}_1\dot{\gamma}_2)$ because the product $(\dot{\gamma}_{c_1}\dot{\gamma}_{k_1})$ associated with the value $[R]^*_p$ at any one value of density D_1 will be left unchanged and may, hence, be replaced by a factor K. This substitution results in the more useful expression

$$[R]^*_p{}' = [R]^*_p K\gamma_1\gamma_2 \qquad (47b)$$

which shows the influence of varying the product $\gamma_1\gamma_2$ of the photographic process on the signal-to-deviation ratio obtained in the video channel. Table XIII lists the values obtained by Eq. (47b) for the four conditions shown as curves 1 to 4 in Fig. 63.

Inspection of Table XIII shows that curves 1 and 3 give higher signal-to-deviation ratios $[R]^*_p{}'$ at highlight signal levels than curves 2 and 4 indicating preference for a high negative gamma ($\gamma_1 = 1.54$). At the black level the longer range positive films 3 and 4 are preferred because the value $[R]^*_p$ on curves 1 and 2 are seriously limited by deviations $[R]_{23}$ contributed by the positive film (see Table XII). A 16mm positive film having a finer grain than the 5203 negative ($[R]^*_{23}$ increased by at least a factor of two) is, therefore, desirable for video recording because it practically eliminates the limitation by $[R]^*_{23}$. Good ratios $[R]^*_p$ in the high- and medium-transmittance range of the motion picture film are most important to reduce the visibility of film grain.

When a sharp kinescope image with separated raster lines is recorded on film the equivalent rectangular cross section $s = V/N_{e(0)}$ of the lines in the negative film may be smaller than the raster line distance V/N_r, where $N_{e(0)}$ = cascaded aperture passband of kinescope,

Table XIII. Signal-to-Deviation Ratios of Photographic Constant Gamma Processes for Video Recording.

	$[R]^*_p$	$[R]^*_p{}'$ (Eq. (47b))			
Curve No. in Fig. 63	$D_2{}^* = 0.25, 1.25, 2.25$	Highlight level ($D_2{}^* = 0.25$)	Black level ($D_2{}^* = 1.25, 2.25$)	$\gamma_1\gamma_2$	$\Delta D_2{}^*$
1	40.4 24.8	31	19.1	0.77	1
2	32 24	24.6	18.5	0.77	1
3	25.8 18.2	39.8	28	1.54	2
4	18.4 17.1	28.4	26.2	1.54	2

camera lens and negative film; V = vertical frame dimension, and N_r = number of raster lines in V (see Part I, Sec. B8, p. 160). In this case the exposed frame area and the number of utilized grains in the negative film are reduced by the factor $K_1 = N_r/N_{s(a)}$ resulting in a reduction of the normal signal-to-deviation ratio $[R]_1$ from the negative to $[R]_1\sqrt{K_1}$. After transfer of the image to the positive film the cascaded value $N_{s(a)}$ includes the aperture of the positive film. The new factor K_2 changes, therefore, the ratio $[R]_2$ from the positive which becomes $[R]_2\sqrt{K_2}$, but it does not alter the above value $[R]_1\sqrt{K_1}$. The signal-to-deviation ratios in a video film-recording process have normal values when K_1 and K_2 are equal or greater than unity, but they are reduced to lower values than given in the previous discussion when the factors K_1 and K_2 are smaller than unity.

The conditions for optimum signal-to-deviation ratios may be summarized as follows:

(a) In both negative and positive films the minimum densities should be as low as possible and the density ranges (ΔD) should be as large as possible without conflicting with the operating requirements of the television system which limits the maximum density range ΔD_2 in the positive and makes a constant product $\gamma_1\gamma_2$ desirable for adequate exposure latitude. The value ΔD_2 may be varied within wide limits when the positive film has a substantially finer grain than the negative.

(b) The negative gamma should be as high as possible, a high gamma being obtained by selection of a film type with a larger grain number and not by over-development of a low-gamma film which may give a higher gamma by increasing the grain size. In practice the requirement for high gamma is tempered by the decreasing exposure lattitude, a short range Δ log E_1 permitting, in general, a higher negative gamma.

(c) The positive film should have a finer grain than the negative film (by a factor of two or more).

6. Luminance Fluctuations and Optical Passbands of Motion Pictures

Twenty-four different phases of the deviations in the positive film are shown every second in a motion picture projection. The static deviations in the film frames are transformed into luminance *fluctuations* and because of the persistence of vision, the grain structures in successive fields are integrated to some extent by the eye. The deviation ratio $[R]_p$ of the process changes to the optical *luminance fluctuation ratio*

$$[R]_o = s[R]_p \quad (48)$$

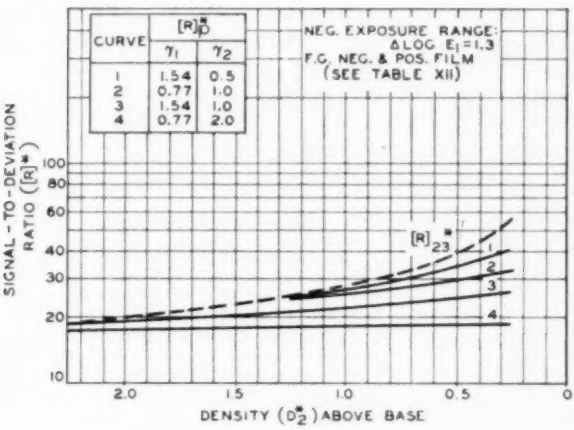


Fig. 63. Deviation characteristics of constant-gamma film process for video recording.

Table XIV. Signal-to-Deviation Ratios ($[R]^*_p$) and Equivalent Passbands ($N_{e(p)}$) of Motion Picture Processes at $D_2 \cong 1$.

Process	N_{sp}	$[R]^*_p$	$[R]^*_p N_{e(p)}$	$N_{e(p)}$/mm	δ_{p_0}	Components		δ_0
35mm motion picture	370	14.9	5510	23.6	45.9	Plus X,	F.G. pos., 4-in. Super Cinephor	(49.5)
16mm motion picture	165	14.9	2460	23.6	45.9	Plus X;	F.G. pos., 4-in. Super Cinephor	(49.5)
16mm motion picture (fine-grain)	323	18.2	5910	46.2	23.4	F.G. neg.,	F.G. pos., High-quality lens	(16.5)
16mm video recording, 20:1 exposure range ($\Delta D_1 = 1.3$)								
$\gamma_1 = 0.77$, $\gamma_2 = 2$, $\Delta D_2 = 2$	285	18.1	5150	40.7	26.5	F.G. neg.,	F.G. pos., High-quality lens	(19)
$\gamma_1 = 1.54$, $\gamma_2 = 1$, $\Delta D_2 = 2$	312	23	7180	44.5	24.3	F.G. neg.,	F.G. pos., High-quality lens	(19)
$\gamma_1 = 0.77$, $\gamma_2 = 1$, $\Delta D_2 = 1$	318	29.1	9250	45.5	23.8	F.G. neg.,	F.G. pos., High-quality lens	(19)
$\gamma_1 = 1.54$, $\gamma_2 = 0.5$, $\Delta D_2 = 1$	353	33.5	11900	50.2	21.5	F.G. neg.,	F.G. pos., High-quality lens	(19)

The storage factor s depends on the ratio of the effective visual storage time T_s to the frame time T_f and is given in first approximation by

$$s \cong (T_s/T_f)^{\frac{1}{2}}$$

The value of T_s is left open for a later discussion, but it can be stated that a value s slightly larger than unity is indicated for the conditions in motion pictures.

The foregoing evaluation of deviations in motion picture film has furnished values which refer to an area a specified by the effective sampling aperture of the process. The effective optical passband has been referred to a unit film area (1 sq mm) as expressed by N_e in lines per millimeter. The $[R]$-values for the film and lens combinations shown in Figs. 57 and 63 apply to all frame sizes of motion picture film. The optical "frequency" characteristic and the equivalent passband N_e, however, must be referred to the particular frame size and are obtained from Figs. 59, 61 and 62 by multiplying the unit line number by the vertical frame dimension V in millimeters. (V = 15.7mm for 35mm film and V = 7mm for 16mm film.) *The granularity in a motion picture frame* is determined by the square root of the total grain number in the picture frame area (see Part I). Expansion of the round sampling area a to the frame area $A = VH$ furnishes the *fluctuation ratio with respect to the film frame*

$$[R]_f = s[R]_p(A/a)^{\frac{1}{2}} = s[R]_p(VH/0.25\pi\delta_o^2)^{\frac{1}{2}} \quad (49)$$

and with δ_o from Table VII:

$$[R]_f = s[R]_p N_{e(p)}(H/V)^{\frac{1}{2}}\dagger \quad (50)$$

The signal-to-deviation ratio $[R]_p$ in

† The numerical value computed with the value δ_o from Table VII differs by a few per cent from this value because of the synthesis of the deviation spectrum from the sine-wave response characteristic (see Sec. 3). Equation (49) is exact when the factor given for aperture #3 in Table IV derived for the sampling equivalent $\overline{N_e}$ is used.

this equation still refers to the equivalent sampling aperture (δ_{p_e}) of the process (see Eq. (45)), or its equivalent passband $N_{e(p)}$. The ratio H/V is the aspect ratio of the film frame. Significant quantities for comparing granularity in 35mm and 16mm pictures are the ratio $[R]_p$ and the line number spectrum (see Figs. 59, 61 and 62), which is indicated by the equivalent passband N_e. Both are needed to define image quality and to predict the appearance and relative visibility of fluctuations to the eye. *The product $[R]_p N_{e(p)}$ combines this information into a single objective figure of merit for the granularity of the process.* The squared value $[R]^2_p N^2_{e(p)}$ expresses by definition the number of samples of energy or matter in the equivalent sampling area a (indicated by its reciprocal N_e^2) and is therefore in agreement with fundamental principles. The significant quantities for a number of motion picture processes are summarized in Table XIV.

When the sampling apertures of the various photographic processes are adjusted to have the same value, indicated by equal equivalent passbands $N_{e(p)}$, the products $[R]_p N_{e(p)}$ remain substantially unaffected. This adjustment can be made, for example, by a change of the projection lens quality (δ_3) or by adding an additional aperture process (δ_4) in cascade such as the process of vision. Leaving a discussion of the subjective impression of graininess to a later publication, it can be expected that the objective measure of granularity $[R]_p N_{e(p)}$ will place photographic processes in an order which is in agreement with visual observations.

APPENDIX

STATIC DEVIATION MEASUREMENTS ON PHOTOGRAPHIC FILM

The optical arrangement shown in Fig. 64 is similar, in principle, but not nearly as elaborate as the one used by Jones and Higgins.[2] The sampling aperture is the image of aperture A formed in the film plane by a coated 14-mm objective I. The film sample is mounted on the stage of a Leitz metal-

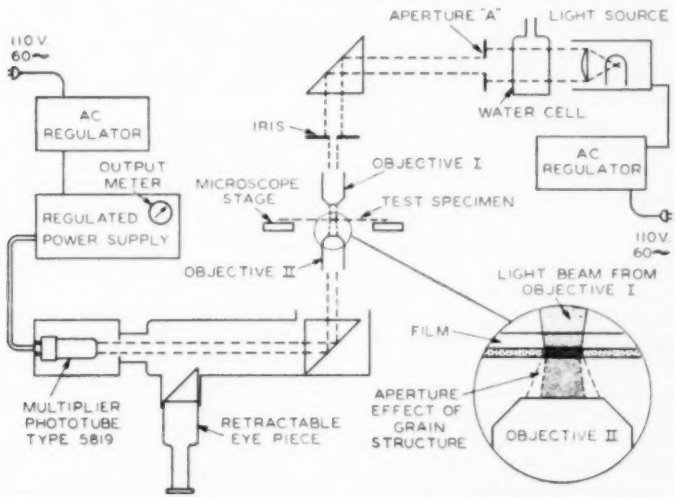


Fig. 64. Apparatus for deviation measurements on photographic film.

lurgical microscope. A second objective II (8mm) below the stage is focused on the aperture image with the film moved out of focus but in the light beam. The film grain is then brought into focus by vertical stage adjustment as observed through the observation eye piece. When the eye piece is retracted the light strikes the photocathode of a multiplier phototube giving an electric current proportional to the total light flux transmitted through the sampling area a on the film. The sampling area a is adjusted by the aperture size A and distance from objective I and measured by removing the phototube and inserting a second ocular to project a magnified image (1000 times) on a ground glass screen (not shown). At any given film density 30 to 60 flux readings are taken along arbitrary cross sections of the film in groups of 10. The readings are averaged and the film is moved to an unexposed area to measure the transmittance ratio τ/τ_o. The deviations $\Delta\tau$ from the mean values are tabulated to determine the rms value $[\Delta\tau]$ and the ratio σ_τ (Eqs. (13) and (33)).

An optical observation of the aperture image with the film in place must be made to check the effective sampling area a. Diffraction or diffusion effects in the developed emulsion introduce an exponential aperture effect which can introduce considerable errors when the sampling aperture is small because it changes the actual sampling aperture to a cascaded value with an effective area larger than the optical image obtained without the test specimen (see insert drawing in Fig. 64). The equivalent aperture diameter of the *developed* film is considerably smaller than that of the undeveloped film (see Table VIII) because of the much higher light absorption by the developed silver grains. The equivalent film aperture increases with emulsion thickness for objectives (I) of shorter focal length and for aperture shapes other than round, and is, in general, proportional to the resolution of the film type. To prevent the aperture error and to satisfy the requirement $\sigma_\tau < 0.1$ (see Eq. (35)) the diameter of the sampling aperture a must be at least three times larger than the equivalent aperture diameter of the developed film type. The sampling apertures used in the measurements reported in this paper fulfill this requirement. Many discrepancies reported in the literature for small sampling apertures are readily explained by the aperture error.

Acknowledgments

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Color Negative and Color Positive Film for Motion Picture Use

By W. T. HANSON, Jr.

A color film for use in an ordinary 35mm motion picture camera is described. This film contains colored couplers which, upon development to a negative, lead to three-color negative records which are almost fully corrected. The development procedures and the sensitometric characteristics are described. The spectral-density characteristics of the individual images are included. This film is printed on a color positive film. The spectral-density characteristics of the dye images obtained in the positive, the development conditions and the sensitometric characteristics of the positive are given. The printing may be done on an ordinary continuous contact printer. However, scene-to-scene color-balance changes require more complicated equipment. The sensitometric characteristics of the sound-track image and the method of developing this image are described. The color positive film may also be used for making prints from black-and-white color-separation negatives.

INTEGRAL TRIPACK three-color subtractive films have been in use in the motion picture industry for a good many years. These films include Monopack, Ansco Color, and 16mm Kodachrome in this country, and the Agfacolor negative-positive film in Germany. The present paper describes a new negative color film and a new positive color film for use in making 35mm motion pictures. The negative film has certain features which have not previously been used in the motion picture field.

Communication No. 1457 from the Kodak Research Laboratories, a paper presented on April 27, 1950, at the Society's Convention at Chicago, Ill., by W. T. Hanson, Jr., Eastman Kodak Co., Kodak Park Works, Rochester 4, N.Y.

The Negative Color Film. The negative film is called Eastman Color Negative Safety Film, Type 5247. It contains couplers similar to those used in the Kodacolor process described in 1942.[1] Each coupler is dissolved in an oily liquid which is, in turn, dispersed in an emulsion. The structure of the film is shown in Fig. 1. It can be exposed in an ordinary 35mm motion picture camera. The ASA speed rating of the film is 16 and it is balanced for exposure in daylight or with high-intensity arcs with the Brigham Y-1 filter. Being a negative film, it has somewhat more

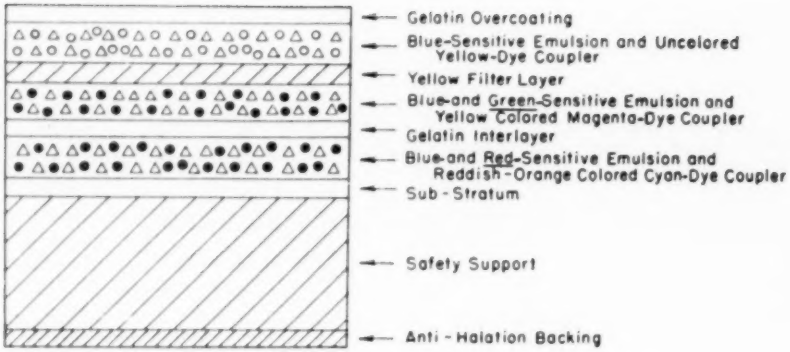

Fig. 1. Schematic cross section of Eastman Color Negative Safety Film, Type 5247.

exposure latitude than most reversal films. One stop overexposure or underexposure can be tolerated with no significant degradation of quality, and two stops overexposure will give a fairly satisfactory result. However, as is the case for practically all color films, the lighting contrast ratio should be from one to two or three and should seldom exceed one to four except where a special effect is desired.

The negative film can be processed in any conventional type of processing machine which has a sufficient number of tanks for the steps that are required, and which has certain tanks that are resistant to the bleaching solution. The processing steps are shown in Table I. The developing agent in the color developer solution is a derivative of *p*-phenylenediamine which does not normally produce "sensitization" in human skin. Its properties in this respect are similar to the well-known Kodak Elon Developing Agent.*

*The exact formulas for the processing solutions must be adjusted for the various processing machines of different design and cannot be specified quantitatively. Information based on the most recent experience is available through the Motion Picture Film Division of the Eastman Kodak Company.

Color Correction With Colored Couplers. The dyes used to form the images in subtractive color processes have absorption characteristics which lead to undesirable results when a color transparency is duplicated or when a color negative is printed to a color positive. The cyan-dye image, for example, which is supposed to absorb only red light, absorbs some of the blue and the green light. The effects of such overlapping absorptions can be minimized or possibly eliminated by the use of separate masks, as described by Miller.[2] However, the procedures involved in using separate masks are extremely tedious. A much more direct and simple method of eliminating the effects of the overlapping absorptions of the dyes is the use of colored couplers.[3-4] Couplers of this type are used in the red- and green-sensitive layers of Eastman Color Negative Film.

The coupler in the red-sensitive layer forms the cyan dye and is colored orange. It has some absorption in the blue and green regions of the spectrum but transmits freely in the red region where the cyan dye absorbs. When this coupler is converted to the cyan dye, the orange color is destroyed. Thus, when a film is exposed and developed, the areas which receive exposure are developed

to a cyan dye, the orange-colored coupler being destroyed. The unexposed areas, in which no development takes place, retain their orange color. Areas of intermediate exposure contain some cyan dye and some residual orange coupler. This results in a cyan negative image and, in the same layer, an orange-colored positive image composed of residual coupler.

The spectral characteristics of various density levels of such an image are shown in Fig. 2. In the red region of the spectrum, successive areas have increasing amounts of density, owing to the increasing amount of cyan dye. In the green and blue regions of the spectrum, successive areas have essentially the same density. Here the increasing densities caused by the increasing amounts of cyan dye are just canceled by the decreasing densities of the decreasing amounts of residual orange-colored coupler. This series of images is expressed in the form of H & D curves in Fig. 3. The densities measured with red light increase with the logarithm of the exposure and give the normal H & D curve of the cyan image. The densities measured with blue and green light, however, are essentially constant at all levels of exposure. This is the desired characteristic of the cyan-dye image.

The green-sensitive layer of Eastman Color Negative Film contains a yellow-colored coupler, which, on development, forms a magenta dye. Here again, exposure and development lead to two images in the layer — a magenta negative image resulting from the destruction of the yellow color in the regions in which exposure and development take place, and a yellow positive image formed by the residual coupler in the unexposed regions.

The spectral-density characteristics of a series of levels of this image are shown in Fig. 4. In the green region of the spectrum, successive areas have increasing green density, owing to the increasing amounts of magenta image dye. In the short-wavelength blue region of the spectrum, successive areas have decreasing density, owing to the decreasing amounts of the residual yellow-colored coupler. However, in the middle of the blue region, at approximately 460 $m\mu$, the decreasing densities of the yellow coupler image are just equal to the increasing densities of the magenta-dye image so that the two images cancel. In the red region of the spectrum, there is practically no density.

These images are expressed in terms of H & D curves in Fig. 5. The densities measured with green light increase with increasing log exposures to form the normal H & D curve. Densities measured with blue light are essentially constant at all levels of exposure. A glance at Fig. 4 will indicate that these blue densities are measured with a filter which has a narrow band of transmission at around 460 $m\mu$.

Spectral-density curves of a series of

Table I. Processing Steps for Eastman Color Negative Film.

Step	Time	Temperature 70 F
Carbonate prebath	1–2 min	Not critical
Negative color development	24–27 min	Critical
Stop bath	4 min	Not critical
Water wash	4 min	Not critical
Bleach	8 min	Not critical
Water wash	4 min	Not critical
Fixing bath	4 min	Not critical
Water wash	8 min	Not critical
Wetting agent	1 min	Not critical
Drying	15–20 min	

Lacquering — bead application (both sides)

Note: Proper development time is a function of agitation conditions and of the particular machine being used. Developer temperature should be controlled to ±0.25 F; other solutions, ±2 F.

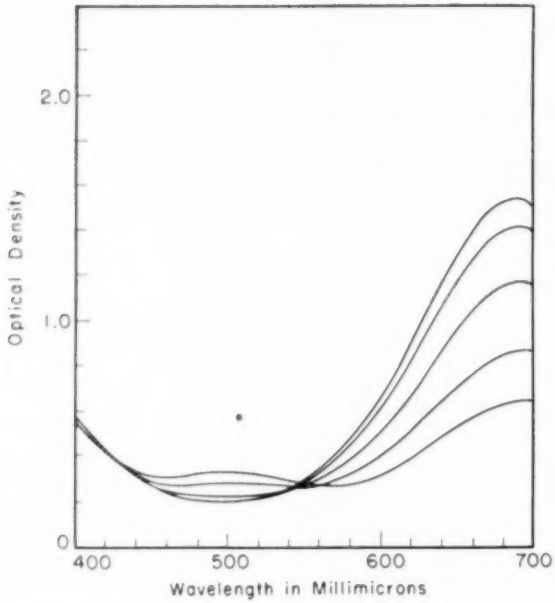

Fig. 2. Spectral-density curves for a series of concentrations of the cyan image of Eastman Color Negative Film.

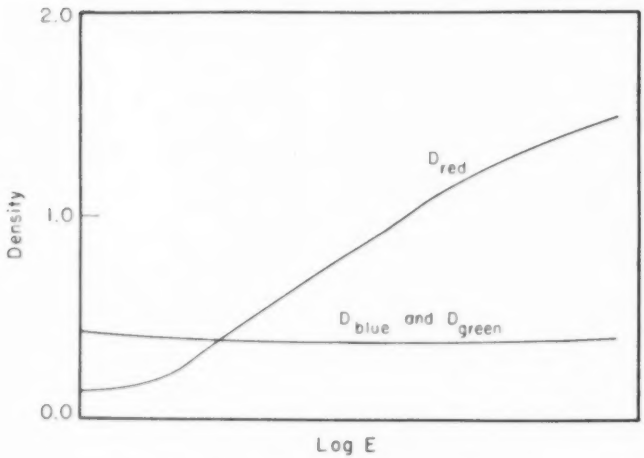

Fig. 3. H &D curves for the cyan image of Eastman Color Negative Film.

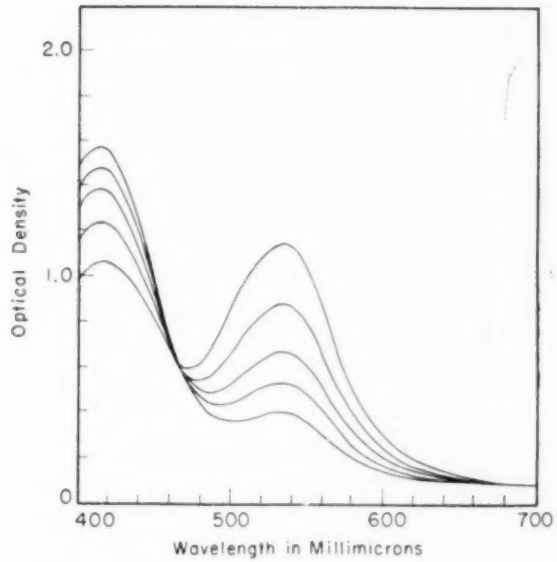

Fig. 4. Spectral-density curves for a series of concentrations of the magenta image of Eastman Color Negative Film.

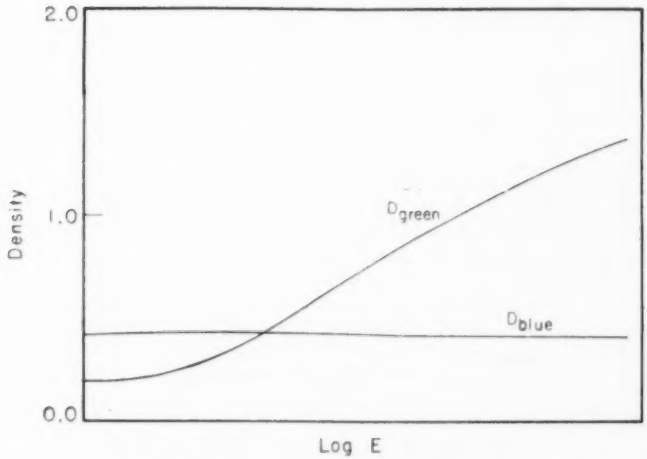

Fig. 5. H&D curves for the magenta image of Eastman Color Negative Film. (Densities to red are insignificant.)

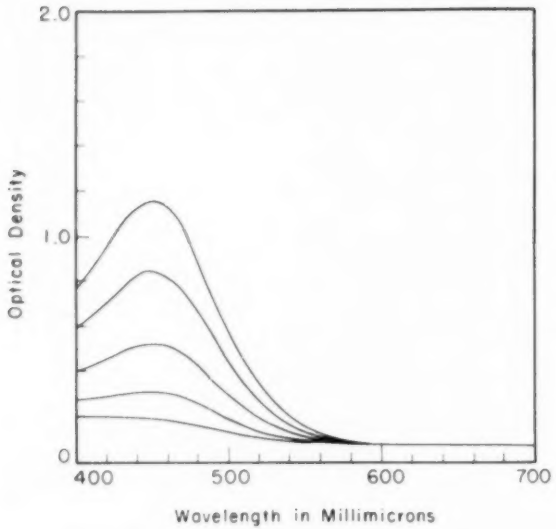

Fig. 6. Spectral-density curves for a series of concentrations of the yellow-dye image of Eastman Color Negative Film.

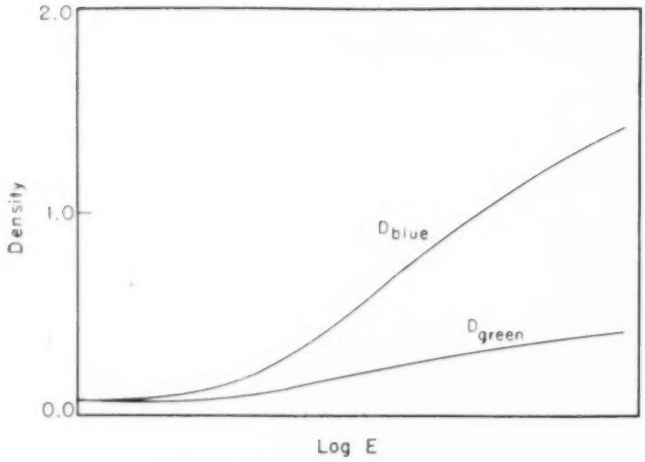

Fig. 7. H &D curves for the yellow image of Eastman Color Negative Film.

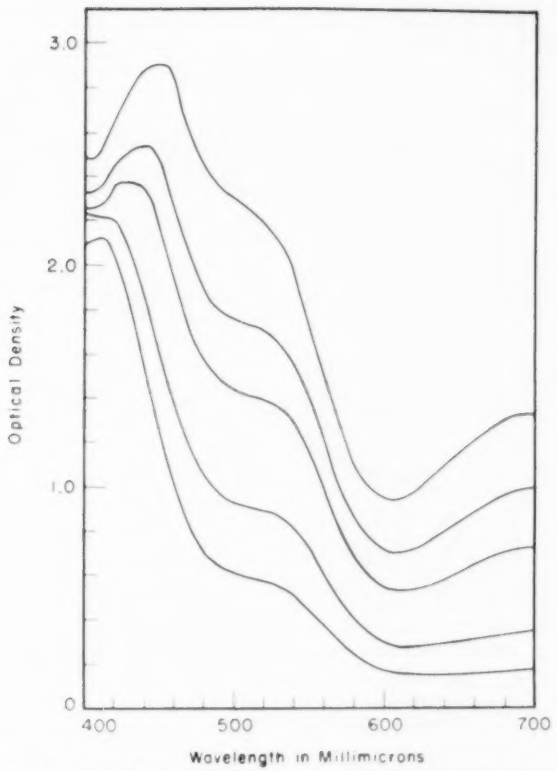

Fig. 8. Spectral-density curves of a series of concentrations of the dyes occurring in the reproduction of a scale of neutrals on Eastman Color Negative Film.

amounts of the yellow-dye image are shown in Fig. 6. In this case, no colored coupler is used. The H & D curves of this image are shown in Fig. 7. The insignificant red densities of the yellow-dye image have been neglected, but there is significant green density, as shown by the curve. It would be desirable to correct this by means of a colored coupler, but to date such correction has not been possible. Such a correction would improve the reproduction of yellows and greens.

The sum of all three of these images is shown in Fig. 8 by the spectral-density curves of the reproduction of a scale of neutrals on Eastman Color Negative Film. Obviously these spectral-density curves do not represent visual neutrals. The reproduction of neutrals is quite orange in color because of the presence of the orange- and yellow-colored couplers. This orange overcast which must occur in all pictures on Eastman Color Negative Film is eliminated in the printing process by the proper sensitization in the print film and the proper selection of light intensity in the red, green and blue regions of the spectrum. However, after such correction has been

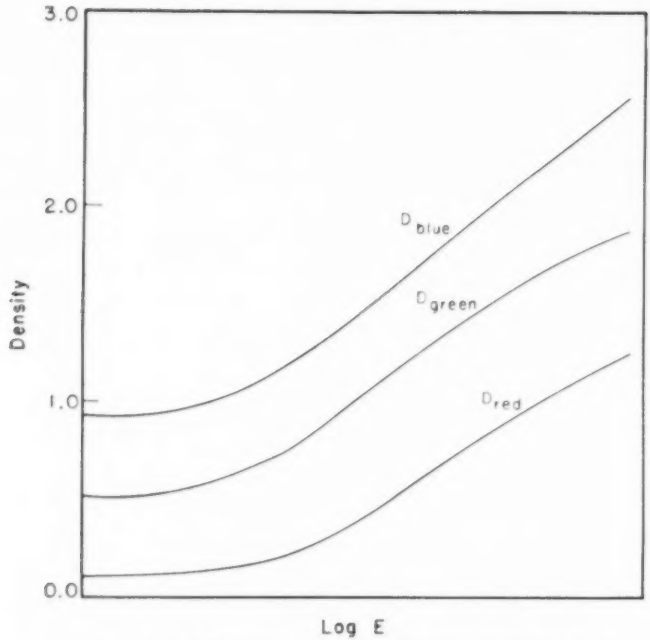

Fig. 9. H&D curves for Eastman Color Negative Film.
Exposure, intensity-scale sensitometer, 1/25 sec;
Illumination, daylight quality;
Density, printing density.

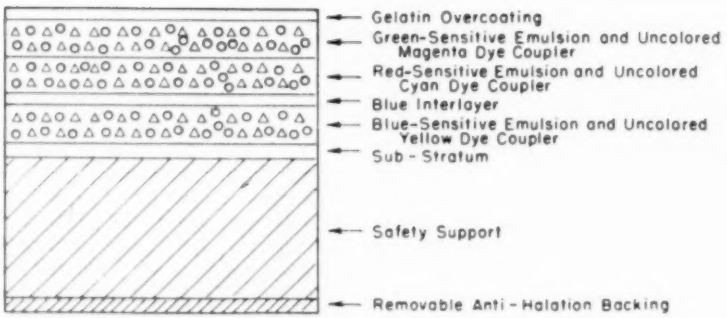
Gelatin Overcoating
Green-Sensitive Emulsion and Uncolored Magenta Dye Coupler
Red-Sensitive Emulsion and Uncolored Cyan Dye Coupler
Blue Interlayer
Blue-Sensitive Emulsion and Uncolored Yellow Dye Coupler
Sub - Stratum
Safety Support
Removable Anti - Halation Backing

Fig. 10. Schematic cross section of Eastman Color Print Safety Film, Type 5381.
(All layers contain a magenta dye.)

made in the printing operation, the final result is free of the defects introduced by the overlapping absorptions of the cyan and magenta dyes in the negative.

The H & D curves for the reproduction of a scale of neutrals on Eastman Color Negative Film is shown in Fig. 9. The three curves represent the densities of the neutral scale as measured with red, green and blue light. These measurements were made through filters with a physical densitometer using a photomultiplier tube with an S-8 sensitive surface. The filters were selected according to the technique described by Williams,[5] with the intention that the densitometer would measure the densities of the image in the same way that the image would print onto the color positive film. Thus, the curves are expressed in terms of printing density. Since these curves are in terms of integral printing densities, they do not represent the separate characteristics of the cyan, magenta and yellow images, but the sum of these three. However, to a first approximation, the red density curve represents the cyan-dye image; the green density curve, the magenta-dye image; and the blue density curve, the yellow-dye image. Here again, the orange-colored overcast of the Eastman Color Negative image is indicated by the high densities to green and the higher densities to blue.

The Positive Color Film. The positive film is called Eastman Color Print Safety Film, Type 5381. It also contains couplers which are dissolved in an oily liquid and dispersed in the emulsions. In this case, however, the couplers themselves are not colored. The structure of this film is shown diagrammatically in Fig. 10. The first emulsion layer is a fairly fast emulsion containing the yellow-forming coupler. It is desirable that this layer be on the bottom, since the yellow-dye image contributes the least to overall picture sharpness and the lower image in a multilayer film is the least sharp. The emulsion is fairly fast so that the negative film with the high blue densities described previously can be printed. The next layer is a blue-dye interlayer. The major purpose of this layer is to absorb red light transmitted by the upper layers. Within all three emulsion layers, light is scattered by the silver halide grains. Scattered red light, as well as direct red light, exposes the red-sensitive layer and thereby causes a decrease in image sharpness. The blue-dye layer underneath the red-sensitive layer absorbs light transmitted by the upper layers and prevents this from being scattered and reflected back to the red-sensitive layer from the bottom layer. There is still some residual scatter in the top two layers which has an effect on sharpness. The next layer is the red-sensitive emulsion

Table II. Processing Steps for Eastman Color Print Film

Step	Time	Temperature 70 F
Carbonate pre-bath	1–2 min	Not critical
Positive color development	12–15 min	Critical
Stop bath	4 min	Not critical
Water wash	4 min	Not critical
Bleach	8 min	Not critical
Water wash	2 min	Not critical
Sound-track development (strip applicator)	10 sec	Not critical
Water wash	2 min	Not critical
Fixing bath	4 min	Not critical
Water wash	8 min	Not critical
Stabilizing bath	1–5 sec	Not critical
Drying	15–20 min	
Edge waxing (both sides)		

Note: Proper development time is a function of agitation conditions and of the particular machine being used. Developer temperature should be controlled to ±0.25 F; other solutions, ±2 F.

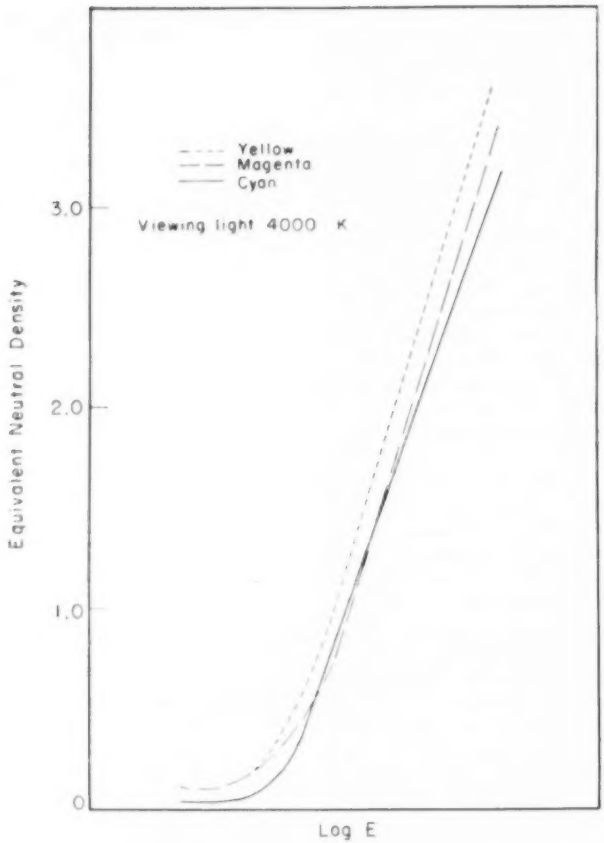

Fig. 11. H &D curves for Eastman Color Print Film. Exposure, intensity-scale sensitometer, 1/25 sec; Illumination, tungsten light plus color-correction filters; Density, equivalent neutral density, calculated from integral density measurements.

containing the cyan coupler. Next is the green-sensitive emulsion containing the magenta coupler. Over this is a gelatin overcoat to protect the film against abrasion. Throughout the entire film is a magenta dye. This prevents green light from being scattered throughout the layers and decreasing the picture sharpness of the magenta-dye image.

The processing steps are shown in Table II.* The developer used for processing the color positive is a deriva-

*The exact formulas for the processing solutions must be adjusted for the various processing machines of different design and cannot be specified quantitatively. Information based on the most recent experience is available through the Motion Picture Film Division of the Eastman Kodak Company.

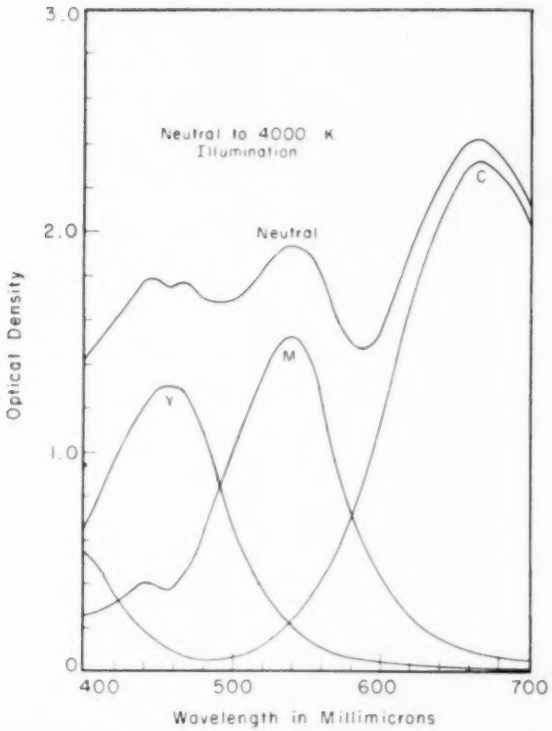

Fig. 12. Spectral-density curves for the cyan, magenta and yellow dyes in Eastman Color Print Film and the neutral they form. Neutral density of 1.72 in 4000 K blackbody illuminant.

tive of *p*-phenylenediamine which is known to produce "sensitization" in human skin. Repeated contact with the developer will lead to "dermatitis." Great care must therefore be exercised in handling this solution.*

After exposure to a step tablet on a sensitometer (the light source being adequately balanced for a particular emulsion), the final processed film may be expressed in terms of the three normal H & D curves of a color film. In order to describe adequately the characteristics of each of the dye images, the densities should be expressed in terms of "analytical" density. For the curves shown in Fig. 11, the densities were read on a physical densitometer through red, green and blue filters and the integral densities converted to equivalent neutral density.[6]

Spectral-density curves of the three image dyes are shown in Fig. 12. These are shown in the amounts which make a neutral density of 1.72 to a blackbody illuminant with a color temperature of 4000 K. Spectral density of the neutral is fairly selective which results in changes in the appearance of the print when the illuminant color is changed. If a print

* Specific precautions which must be followed are available from the Motion Picture Film Division of the Eastman Kodak Company.

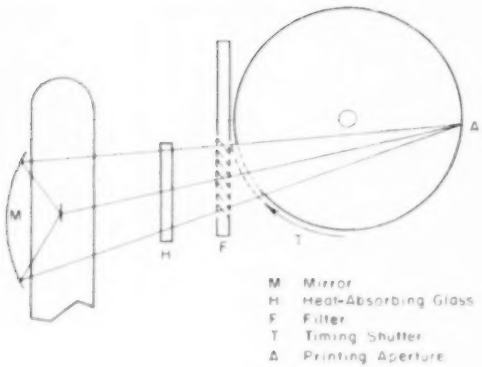

Fig. 13. Schematic illustration of position of filters in light path in Bell & Howell Model D printer.

is properly balanced for arc projection, its appearance will change if a tungsten light source is used.

Printing the Negative to the Positive. As in the case of any integral tripack printing operation, no registration problems are involved in printing Eastman Color Negative Film onto Eastman Color Print Film, and printing can be done on a continuous contact printer. The main requirements are that a light source of sufficient intensity be available and that some means for altering the spectral quality of this light be supplied. Satisfactory results have been obtained using a Bell & Howell Model D printer, with the light source adjusted according to the recommendations of Kunz, Goldberg and Ives.[7] A slot has been cut in the lamphouse casting so that a filter pack may be inserted into the light path at a position shown schematically in Fig. 13. Two pieces of Pittsburgh heat-absorbing glass (No. 2043), 0.1 in. thick, are in the position shown. With a properly exposed negative and a typical print-film raw stock, a 400-w, 115-v lamp operating at 105 v gave satisfactory print density at printer point "12," with the printer operating at the rate of 45 ft/min.

While printing with a continuous tungsten light source, adjusted in color quality by means of color-compensating

Fig. 14. Filter arrangement for "narrow-band" printing: red, Corning #2408, 1 mm; green, Corning #3486 + #4303, 1 mm; and blue, Corning #5113, 1 mm.

filters, usually gives a satisfactory print, it does not give the maximum obtainable color quality. The dyes and the colored couplers in the negative have fairly narrow absorption bands so that the color quality obtained in a print is quite sensitive to changes in the sensitivity distribution of the print film or to changes in the spectral quality of the printing light. Reference to Figs. 4 and 6 shows that the blue density characteristics of the yellow and magenta images change appreciably in the region

of 410 to 460 mμ. The results obtained in the final print are affected noticeably by changing the quality of the printing light in this region of the spectrum. A Kodak Wratten Filter No. 2B, or similar violet-light absorber, should always be used in the printing operation. Similarly, reference to Figs. 2 and 4 shows that the green density characteristics of the cyan and magenta images vary considerably in the region of 520 to 560 mμ, and the density of the cyan image varies appreciably within the red region of the spectrum. Variations of the quality of the printer light in these spectral regions will lead to varying results.

Better control of the color quality of the print can be obtained if the light source used for printing is composed of three spectral bands in the blue, green and red regions of the spectrum. This can be accomplished by mixing the light transmitted by three filters, for example, by introducing into the light beam on the Bell & Howell Model D printer a filter which is composed of a series of strips of glass as shown in Fig. 14. This filter is placed in the light path in the printer at the same position occupied by the color-compensating filters as shown in Fig. 13. This strip construction of the filter provides uniform illumination at the printing aperture. The position of the filter in the beam and the alignment of the mirror must be critically adjusted in order to ensure uniformity at the printing aperture.

In printing by the technique just discussed, it is possible to use the regular timing shutter on the Bell & Howell printer for introducing density corrections from one scene to the next. However, it is not possible to make changes in the color quality of the illumination between scenes in order to correct the color balance of successive scenes. In motion picture color printing, such "color timing" is necessary. This can be accomplished by the use of three light sources in the optical system of a printer such as the Bell & Howell Model D. This is shown schematically in Fig. 15. The light from each lamp passes through a filter, and then the three light beams are combined at the printing aperture. With this system, the narrow spectral bands of light as described above will be obtained. In addition, the intensity of each of the light sources can be adjusted separately by known means, such as varying the voltage, use of diaphragms, or neutral-density filters, and thereby effect the proper color timing. This type of light source has been described by Bornemann and McKusick.[8]

Eastman Color Print Film can also be printed from color-separation negatives. In this case, the printing must be done in a step printer with adequate registration pins. Negatives obtained from Eastman Multilayer Stripping Negative Safety Film, Type 5249, described by Capstaff,[9] are a typical example. Similarly, separation positives and duplicate separation negatives may be made from Eastman Color Negative and these, in turn, printed onto Eastman Color Print Film or some other color film.

Sound Track. The sound track on Eastman Color Print Film is developed by edge application of a reducing agent* after the rehalogenizing bleach bath. In the color developer, the sound-track and picture images are developed simultaneously to dye and metallic silver. The next step in the process removes all of the unexposed silver halide in both picture and sound-track areas. Following the fixing bath, the bleach bath converts all of the developed silver image to silver bromide. In the sound-

* The exact formulas for the processing solutions must be adjusted for the various processing machines of different design and cannot be specified quantitatively. Information based on the most recent experience is available through the Motion Picture Film Division of the Eastman Kodak Company.

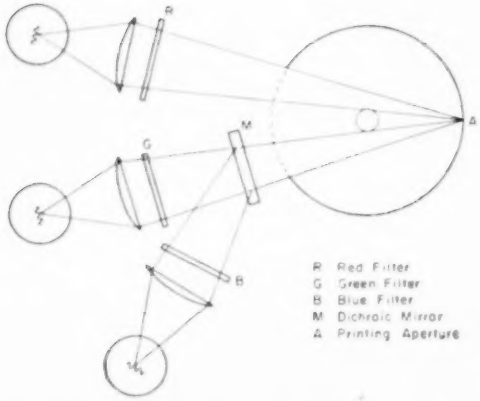

Fig. 15. Schematic illustration of three colored light sources for "color timing" with Bell & Howell Model D printer.

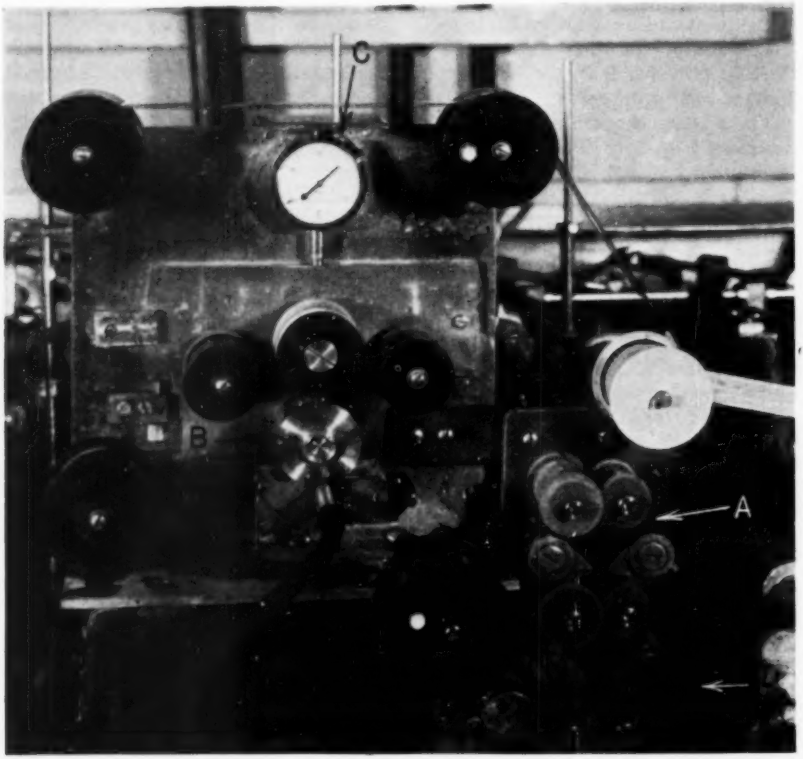

Fig. 16. Sound-track processing: A, air squeegee; B, applicator roller; C, dial indicator for adjusting applicator; and D, film enters wash tank.

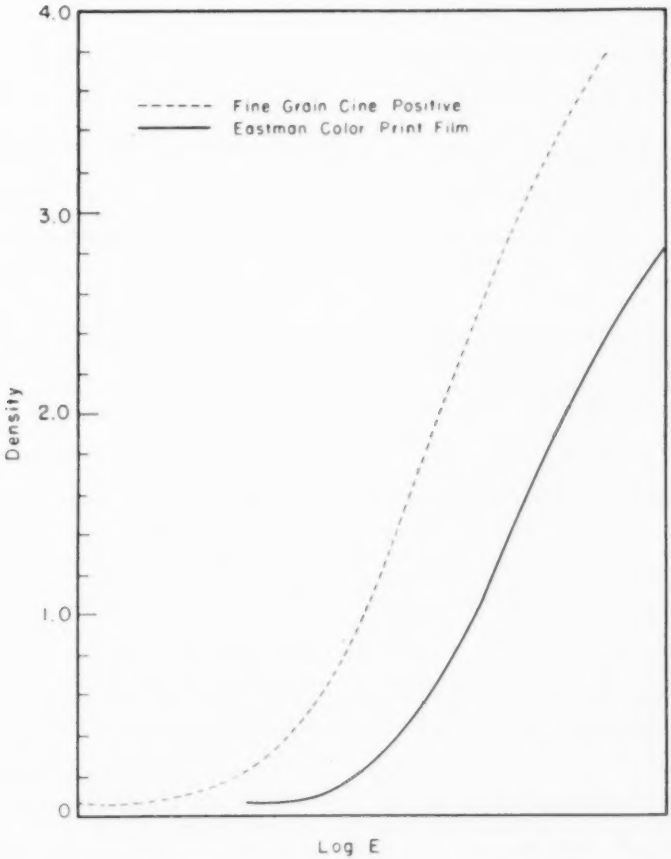

Fig. 17. H & D curves of sound-track images.
Density, ERPI Densitometer with infrared-sensitive cell;
Exposure, Eastman Color Print Film, tungsten light plus color-correction filters for neutral dye image;
Eastman Fine-Grain Cine Positive Film, tungsten light.

track area, this silver bromide is again reduced to metallic silver by an edge-application treatment. The sound track is thus composed of a combined dye and silver image. The edge-application equipment is shown in Fig. 16.

The H & D characteristics of the sound-track image are a function of the color of the light used in exposing the sound track. The highest contrast is obtained if this light is of the color quality which gives a neutral dye image. With such exposure, the density scales of the silver images in the three emulsion layers coincide. Under these conditions, the H & D curve as measured with the infrared-sensitive photocell is as shown in Fig. 17.

An analysis of the characteristics of the sound track on this film has been reported by Evans and Finkle.[10]

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Printer Control in Color Printing

By C. A. HORTON

The use of an electronic photometer is described for maintaining color and intensity balance in 35mm color printers. Some precautions are given on the use of color-correcting filters and data are provided on the hue shift with temperature and consequent reduction of transmission of certain glass filters.

PRINTING OF motion picture color film brings with it problems which do not arise in black-and-white printing. There, it is usually enough to specify an exposure adequate to produce a definite, easily measured, minimum density in the print. The choice of print stock and processing conditions determine the contrast and tone reproduction from a given negative. In color printing, the quality of the printing light must be controlled even more closely than its intensity. The problem in printing a color film is to adjust and maintain an illumination in the printer gate which will produce a pleasing picture on the theater screen.

These strict requirements are especially true in negative-positive systems where the process gamma of the print stock may approach 3.0. The tolerances which have been found necessary are 0.05 log I on illuminance and 0.02 log I on color changes. Such variations as these, or larger ones, may easily arise from aging of the printer lamp, breaking and, hence, replacement of the heat-absorbing glass, or instability of the absorbers in the color filters being used. An accurate and reproducible method of measuring the quality and intensity of the light in the printer gate is almost indispensable. A convenient photometer for printer control should have a linear scale, a stable zero, a wide sensitivity range and freedom from fatigue, and should be easily fitted into the printer gate.

The use of a photronic cell and a galvanometer for control of 16mm Kodachrome printers has been described to this Society by Aex in 1947.* However, the cell fatigue and the short scale of this instrument make it unsatisfactory for controlling printers using high-gamma materials.

The Densichron† shown in Fig. 1 has been found to satisfy most of the above requirements. It consists of a photocell in an a-c magnetic housing, connected to an a-c amplifier with a logarithmic re-

Communication No. 1351 from the Kodak Research Laboratories, a paper presented on April 28, 1950, at the Society's Convention at Chicago, Ill., by C. A. Horton, Eastman Kodak Co., Kodak Park Works, Rochester 4, N.Y.

* Paul S. Aex, "A photoelectric method for determining color balance of 16-mm Kodachrome duplicating printers," *Jour. SMPE, 49:* 425–430, Nov. 1947.

† Manufactured by the Welch Scientific Company.

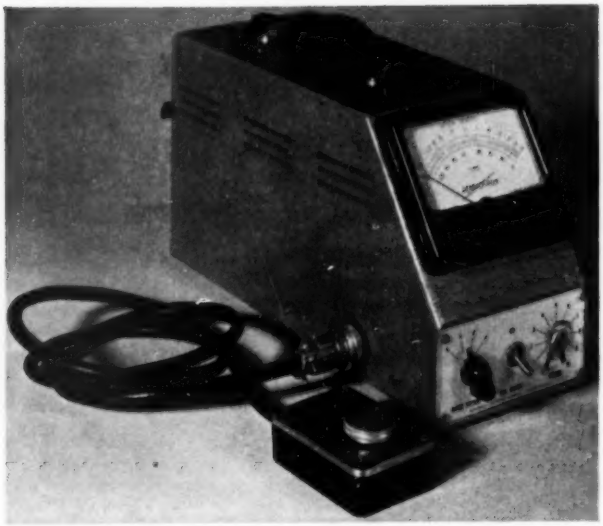


Fig. 1. Densichron and photocell unit.

sponse meter. It is available with either red- or blue-sensitive photocells. The blue cell has been found sufficiently sensitive to measure printer lights through red, green or blue filters. The logarithmic scale is convenient since it may be interpreted directly as log *I*. Its scale has been found to be linear to better than 0.10 over a log *I* range of 2.8, as shown in Fig. 2. In all parts of the scale, fatigue is less than 0.01 log *I* over a three-hour period.

In order to use the instrument as a photometer, some constant source of light is needed as a reference zero. For printer control, the absolute value of the light need not be known. A small battery-operated lamp connected through a milliammeter is adequate or, if a standard sensitometer is available, its direct beam may be used. It is advisable to take readings of the zero of the instrument through tricolor filters in order to detect any relative change in photocell sensitivity. These tricolor filters will be referred to as "analyzing filters." By having such readings recorded it is always possible to adjust the gain to correct for slow drifts in overall sensitivity or an accidental movement of the gain control. The present instrument has been in use six months without showing any change in relative sensitivity.

The choice of tricolor filters for analyzing the light should be determined from the print-film sensitivity and the photocell sensitivity. Ideally, the product of the values of the photocell sensitivity and the transmission of the filters should match the film sensitivity. Since neither of these sensitivities is usually known accurately, it is fortunate that this requirement does not have to be fulfilled strictly.

When printing is being done through filters which produce narrow spectral bands, the analyzing filters may be any set, provided they isolate the same red, green and blue regions of the spectrum as are used in the printer. When printing with white light, or white light modified by color-compensating filters, the choice

is more limited and care must be taken to choose filters which give, with the photocell, a response close to the peak of the film sensitivities. No specific rules for the selection of the filters can be given except that a set is satisfactory if it predicts filter changes that agree with photographic tests. Once a set of filters has been decided upon, it may be used as long as the print material has the same sensitivity distribution.

The most satisfactory filter set found for control of printers using Eastman Color Print Safety Film, Type 5381, was: red — Kodak Wratten Filter No. 70; green — Kodak Wratten Filter No. 16 + No. 61; blue — Kodak Wratten Filter No. 35 + No. 38A. With this set, predictions or transfer of color and intensity balance from one printer to another are correct to 0.02 log E when printing through color-compensating filters. When transferring a balance from this condition to a printer equipped for printing with narrow spectral bands, prediction is correct to about 0.05 log E. The set of narrow-band printing filters used was: red — Kodak Wratten Filter No. 29; green — Kodak Wratten Filter No. 16 + No. 61; blue — Kodak Wratten Filter No. 35 + No. 38A + No.2 A.

In addition to the tricolor filters, the present instrument has a small disk of flashed opal and one of Corning 9780 infrared-absorbing glass 1½ mm thick over the photocell. These are necessary when using the instrument as a color densitometer since the dyes have little density to the infrared. These precautions are probably not necessary when using the photocell as a photometer, but no tests have been made to verify this conclusion.

The Densichron probe containing the photocell is small enough to fit easily in the gate of a Bell & Howell printer. By rotating the probe slowly through a small angle, it is quite easy to get a reproducible maximum intensity reading. In some printers where the probe does not fit in the gate, a curved rod of transparent plastic may be used to conduct the light to the cell. In this case a mechanical guide should be used to locate the probe and rod in the gate, since it is difficult to get reproducible readings when the assembly is held by hand.

When a printing balance is known on one printer, or exposing device, it is frequently necessary to set up the same balance on other printers. By making the appropriate changes in the tricolor readings from the first printer to compensate for differences in speed or time of exposure, these new readings may be set up on the second printer by adjusting the filter pack and timing shutter until the Densichron shows the desired values. This procedure usually brings the printer in balance or so close to it that one photographic test is adequate before starting the printing of full-length pictures.

When a printer test is off balance or shows improper exposure, and density readings on the print, or experience suggests that a change should be made in the printing light, the photometer is more reliable than the catalog densities of the compensating filters. Figure 3 shows spectrophotometric curves of a well-known set of compensating filters. Inspection of these curves shows that the addition of a Kodak Color Compensating Filter CC-50C to the filter pack would seriously disturb the blue and green light balance as well as make the desired correction to the red intensity. By taking red, green and blue photometer readings before and after each filter change, the balance may be corrected exactly to the prescribed set of values. The densities of the complete set of color-compensating filters as read by the Densichron through the filters given are listed in Table I. If measurements are not made by a photometer in the printer gate, these values may be used to estimate the amount of neutral density being introduced in the light beam by the addition of one or more of these filters.

For printer control, daily readings are made through red, green and blue filters

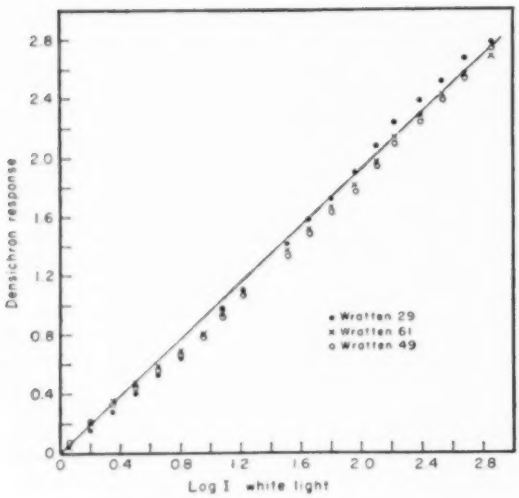


Fig. 2. Linearity of Densichron response.

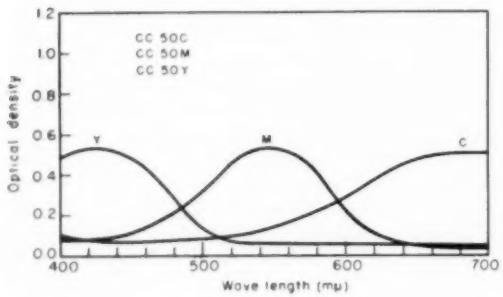


Fig. 3. Spectrophotometric curves of color-compensating filters.

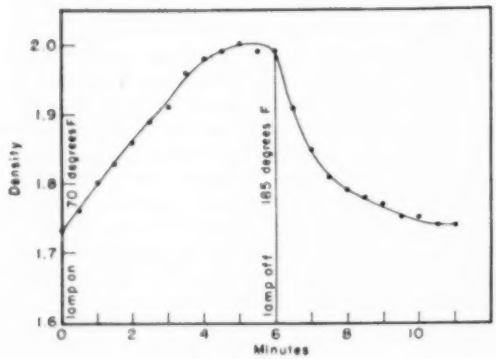


Fig. 4. Density change of red glass filter, Corning No. 2408, Melt 1151, with rise in temperature.

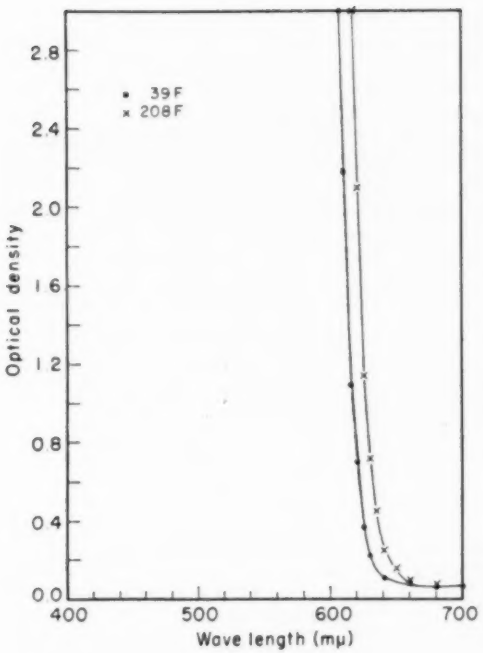


Fig. 5. Shift in the absorption of a red glass, Corning No. 2408, Melt 1151, with change in temperature.

Table I. Densities of Color-Compensating Filters as Measured by the Densichron Through the Tricolor Filters Shown.

Designation	Density to Kodak Filter No. 29	No. 61	Wratten No. 49
CC-05C	0.06	0.04	0.04
CC-10C	0.10	0.04	0.04
CC-20C	0.16	0.05	0.05
CC-30C	0.28	0.07	0.06
CC-40C	0.33	0.08	0.06
CC-50C	0.43	0.09	0.06
CC-05M	0.03	0.06	0.05
CC-10M	0.03	0.10	0.06
CC-20M	0.04	0.16	0.08
CC-30M	0.05	0.28	0.10
CC-40M	0.05	0.31	0.12
CC-50M	0.06	0.47	0.13
CC-05Y	0.03	0.03	0.09
CC-10Y	0.03	0.03	0.12
CC-20Y	0.03	0.03	0.23
CC-30Y	0.03	0.03	0.30
CC-40Y	0.03	0.04	0.37
CC-50Y	0.03	0.04	0.44

of the illuminance in the gate, with and without the printer-balancing filters in position. A comparison of these six readings with those of a previous day's will show whether slow drifts are due to lamp or to filter changes.

Special care must be taken if glass filters are used in the printer, since many of them, particularly the reds and yellows, show a large change in density with temperature. This difficulty has been met with in the use of both Corning No. 2408, Melt 1151, and Corning No. 3384, Melt 600, glasses. The decrease in transmission of the filter as measured by the Densichron may amount to 0.25 log I between room temperature and printer-operating temperature. Figure 4 shows a typical curve of density to red light against time for a Bell & Howell printer with Corning No. 2408, Melt 1151, in the beam. The equilibrium temperature reached at about six minutes was 185 F.

This change of density of glass filters is, in general, due to a movement of the absorption edge toward longer wavelengths with increasing temperature. Spectral-density curves for the above-mentioned red glass at two different temperatures are shown in Fig. 5. Though inconvenient, this density change with temperature need not reduce the accuracy of the printer control if sufficient time is given for the filters to reach temperature equilibrium before readings of the intensity are made.

When printing through narrow-band filters, such as are used in making duplicate positives from a color negative or printing duplicate positives or negatives on a color print film, the analyzing filters should still be used in addition to the printing filters.

When it is necessary to change to a print emulsion whose relative red, green and blue speeds are different from those of the emulsion previously used, the speed differences determined from sensitometry may be applied directly to the tricolor readings and the filter pack adjusted as indicated by the photometer. Similarly, if densitometry of the negative predicts timing changes to red, green and blue, these may be set up on the printer by means of the photometer.

Desirable Characteristics of 16mm Entertainment Film for Naval Use

By LOWELL O. ORR and PHILIP M. COWETT

Current 16mm release prints are evaluated for sound quality, chiefly by measuring dynamic range. Projection equipment and conditions are described.

WE HAVE GATHERED DATA on the quality of 16mm entertainment film release prints as we have found it at the Navy Motion Picture Exchange, Brooklyn. By way of comment, and in order to narrow the issues to be presented, we should mention that the 16mm films discussed here are those resulting from reduction of 35mm entertainment films which are circulated to all commercial motion picture theaters, and further, that such 16mm prints are not used by the Navy alone, for equal numbers are used by the Army and Air Force Motion Picture Service, and approximately half as many by the Veterans Administration. In addition, they are being used on commercial ocean liners, and in various foreign countries. We have every reason to believe that in such various uses, exhibition conditions are such that, while not exactly the same as those prevalent in the Navy, they are nevertheless similar to, and in many cases closely approximate, those of the Navy. We would further like to point out that in referring to the producer herein, we mean the actual producer, or releasing distributor, who is the prime contractor under Navy Motion Picture contracts. As such, the prime contractor is solely responsible for the quality of the release prints supplied.

In undertaking our study we felt that good results could be obtained from presenting a systematic analysis of prints as presently released for Navy use. It is not our intention to be hypercritical, but rather, through the relation of our observations, to tend to indicate what the current practice is with respect to the sound quality of 16mm entertainment motion picture release prints.

It is a truism that, before any suitable improvement in quality can ensue, a true picture must be had of the situation existing at this time. That, then, is our motivation: to establish a plateau, you might say, representing the current practice in 16mm film production.

Presented on October 17, 1951, at the Society's Convention at Hollywood, Calif., by Lt. Lowell O. Orr, USN, New York Naval Shipyard, c/o Motion Picture Exchange, Brooklyn 1, N.Y., and Philip M. Cowett, Dept. of the Navy, Bureau of Ships, Washington 25, D.C.

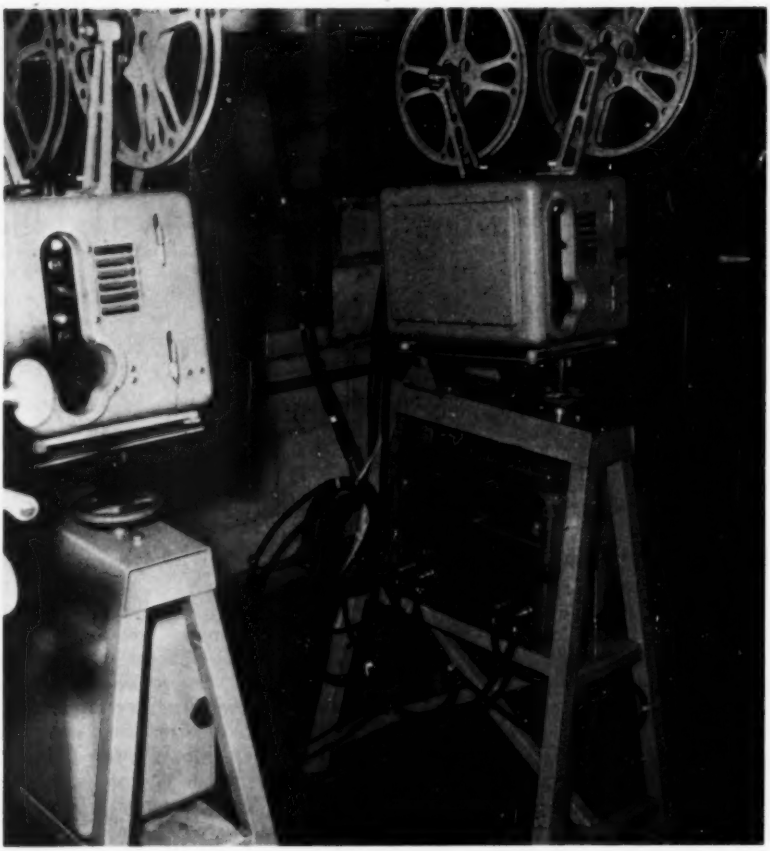


Fig. 1. Standard Navy 16mm IC/QEB projector set.

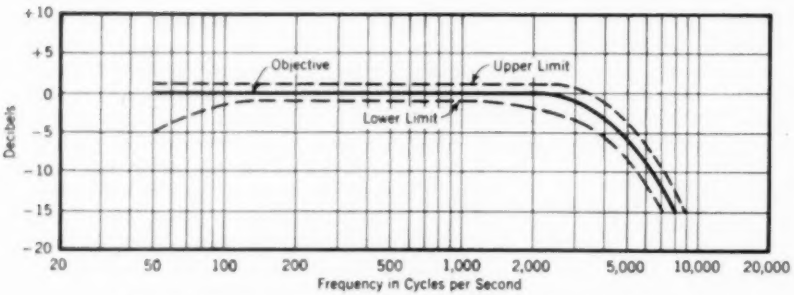


Fig. 2. 16mm sound reproducer electrical characteristic.

Short Form Specification

16mm Review Rooms and Reproducing Equipment

Amplifier Power Output:

10 w, 1% distortion
15 w, 2% distortion
Over passband, 50 to 7000 cycles

Signal-to-Noise Level:

50 db below 10-w level signal from 400-cycle SMPTE standard level film

Frequency Response:

As given in SMPTE recommendations

Uniformity of Scanning-Beam Illumination:

1½ db using SMPTE test film

Flutter:

0.25% peak using SMPTE test film and RCA field-type flutter meter

Fig. 3. SMPTE specifications for reproducing equipment.

We, in the Navy, have problems that are somewhat different from those of the normal user of 35mm entertainment film in that the situation in which the film is reproduced is generally far from desirable. We, for example, exhibit film topside, where high ambient noises caused by exhaust blowers, noises of the ship underway and cross winds, all tend to force a limited dynamic range for optimum intelligibility. A further situation of reproduction which is quite common is that encountered aboard an aircraft carrier, where high ambient noise (80–90 db) results in the net end of masking low-level sequences completely and, unless the print is one of high intelligibility, preventing understanding of much significant dialogue.

As a basis for understanding the data on quality, we should first describe the type of equipment used in the screening room and the exact installation with regard to how the various measurements were made and how our data were obtained. This equipment is the standard Navy 16mm IC/QEB projector set (Fig. 1), manufactured by the De Vry Corporation and designed to conform to the requirements, regarding its frequency-response characteristic (Fig. 2), as set forth by the 16mm Subcommittee on Sound Reproduction (Fig. 3). It has a power-output capacity of 20 w at less than 2% distortion over the passband of frequencies (Fig. 4). The frequency-response and tone-control characteristics of the amplifier are shown in Figs. 2, 5 and 6. Similarly, the portable loudspeaker frequency-response characteristics are shown in Fig. 7.

In order to evaluate prints as to dynamic range, we utilized a second amplifier which was bridged directly across the sound output from the two projector sound heads. The function of this second amplifier was to operate the volume-level indicator which is incorporated in a still projector and is

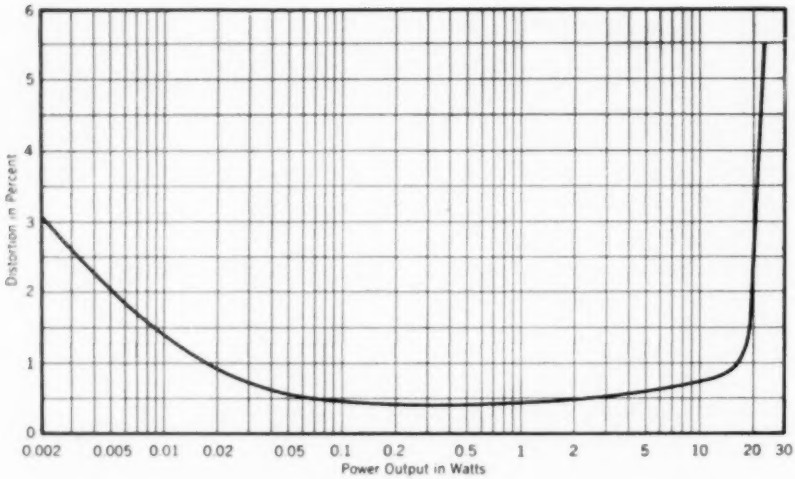


Fig. 4. Amplifier total harmonic distortion versus power output (frequency range 100 cycle/sec to 5000 cycle/sec).

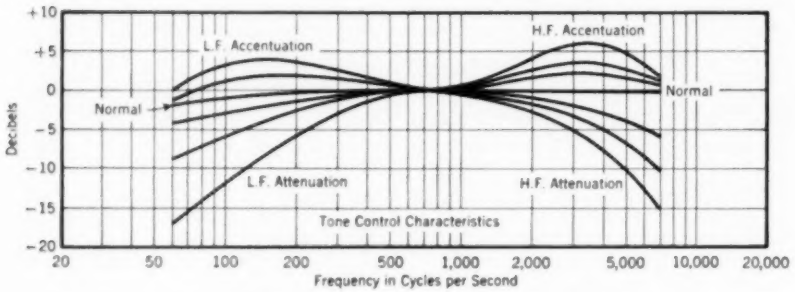


Fig. 5. Amplifier tone control characteristics.

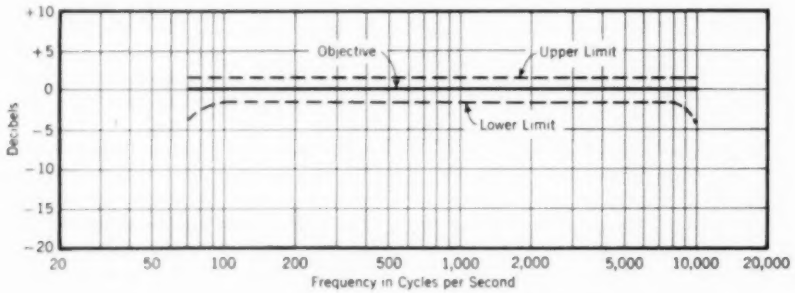


Fig. 6. Amplifier frequency response design limits.

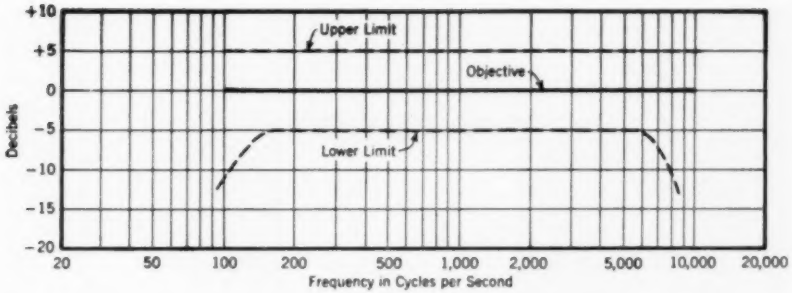


Fig. 7. Loudspeaker acoustical response frequency design limits.

identical with what is used in the review rooms in Hollywood. The VU (volume unit) meter is calibrated as to the zero-level reading by reproducing the SMPTE 400-cycle standard-level film. The dynamic-range amplifier is adjusted to indicate full scale on the volume-level indicator when using this level film. This was necessary to enable us to measure low-level dialogue sequences on the film, which would give no meter indication whatsoever if a zero-level meter setting were used.

The Motion Picture Exchange review room as shown in Fig. 8 is 60 ft long, 30 ft wide and 20 ft in height. It is made of cinder block which supplies some acoustic deadening. Therefore, our screening room is not unlike most of those in Hollywood, with the single exception that it is somewhat more reverberant. The 16mm projection equipment used in the screening room is identical in performance with that of standard review-room 35mm projection equipment.

Use of Sulfide Photoresistive Cell

One more factor of interest, to us at least, and a very important factor, was that we had pioneered, in the IC/QEB equipment, with the use of the sulfide photoresistive cell. Our reasons for using the cell were to secure a wider frequency range, higher signal-to-noise level, elimination of photocell hiss, elimination of photocell microphonics and the elimination, in the sound head itself, of high impedances which are always a source of trouble in high humidities.

In order to corroborate our thinking with regard to the use of this cell, and to check its overall performance, two projectors were used in the evaluation of film. One projector contained the conventional cesium photoelectric cell, while the second projector was equipped with a sulfide photoresistive cell. Both of these projectors were then adjusted in output level, using the Society's 400-cycle standard level film, so that they gave the same reading on the VU meter. It then became standard practice to screen all film on the two projectors in order to determine any difference in the reproduction of film from either one of the cells. We have amassed considerable data on the various film producers' products in this manner and can state that, with the exception of dye tracks, there is no difference in the performance between the sulfide cell and the cesium cell. The blue dye track develops a signal of 5 db to 10 db less than the silver track. No other significant changes in print sound quality exist. The cell comparison data could have been presented, but have not been since there was no difference in performance other than as noted.

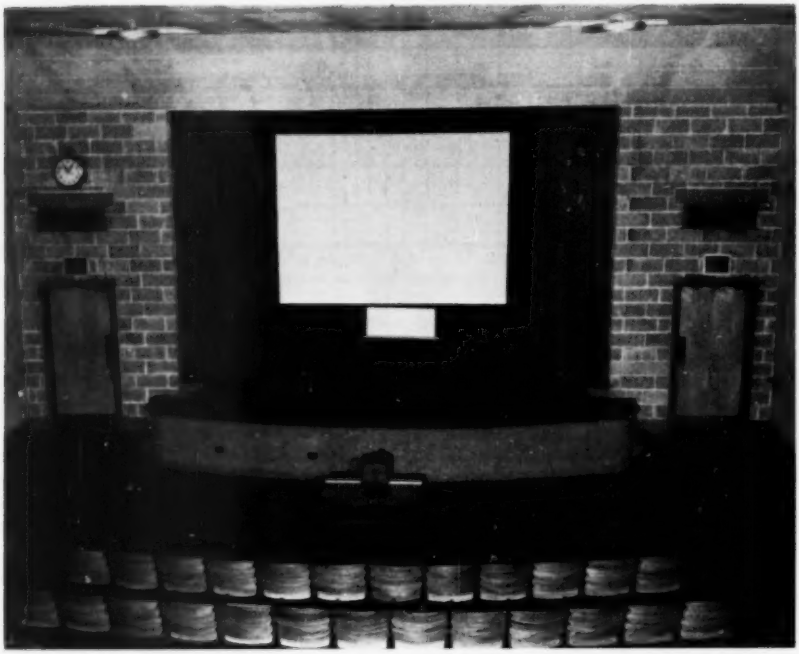


Fig. 8. Motion Picture Exchange review room.

Now, getting back to our problems with regard to high ambient noise, and the masking effect of such noise on low-level sequences, we desired to set up a test condition at the Motion Picture Exchange that would simulate quite closely conditions encountered in the field. Therefore, since we have recordings at the Material Laboratory in the New York Naval Shipyard of all types of ships' noises, used for determining the best frequency characteristics of battle-announce equipment, etc., it was convenient for us to procure records of these ships' noises and, through a reproducer system set up in the screening room, duplicate conditions aboard ship.

We also have very accurate data on the intensity of the noise at various parts of a ship, so it was not necessary for us to leave the screening room in order to determine the best dynamic range of a print. We emphasize the above because one of the most significant faults with prints, as released to us, has been the tendency to use an extremely wide dynamic range on the assumption that the film is going to be listened to in a theater, under optimum listening conditions, where such a range is practical. Now that we have established the test condition, we would like to point out that this study was made possible through cooperation and collaboration with the Society of Motion Picture and Television Engineers and more especially with its Subcommittee on 16mm Sound Reproduction.

The factor of print quality, insofar as distortion is concerned, or frequency range, having to do with the naturalness of the sound, and the overall quality

of the sound have all been carefully considered in our analysis of prints. The quality of sound, of course, is not subject to any method of measurement and, in a sense, is a matter only of the listeners' acceptance of what he considers good quality. Our discussion here, therefore, deals not with this phase of print quality, soundwise, but purely with the factor, more important to us for the moment, of the dynamic range in release prints. In securing these data we had the opportunity, as you may appreciate, of working with specimens from every major producer. The producers are not identified by name, but are marked in such a way that we can identify their respective products. In Table I are the data for both black-and-white and color, including both variable-area and variable-density tracks. The maximum peak, derived from the volume indicator, is given in terms of decibels below the selected zero level as indicated below. The average peak is also in terms of decibels. The minimum peaks, or the low-level parts, are not indicated here, as they are in many cases too low in level to show on the instrument.

From these data the reader will appreciate that low-level dialogue sequences would be completely masked by any distracting noise or poor acoustical conditions. It is our hope to have film in the future in which this will not be the case. We have, then, an analysis of thirteen producers' products with regard specifically to dynamic range. As presented in Table I, these products indicate what the current practice is with respect to the dynamic range of 16mm entertainment film release prints.

To establish a basis for comparison with the data in Table I, the measurements on the current SMPTE 16mm Sound Service Test Film Type SPSA are given in Table II. Table III is a summary average of the data contained in Table I. By way of further analysis there are shown in Table IV the most and least favorable readings taken in this survey of both types of sound tracks in black-and-white and color. It should be noted that the producer of a "best" sound track is also capable of producing a "worst" sound track.

From the preceding it can be seen that to reproduce satisfactorily all prints offered to the Navy, the equipment would have to be designed with a reserve gain of at least 25 db. That, then, means that particular color prints are 20 db below standard black-and-white prints as released for system check by the Society of Motion Picture and Television Engineers.

The preceding data on the dynamic range of current release prints are the basis for experiments conducted at the Motion Picture Exchange in determining an acceptable degree of compression of the dynamic range.

The synthetic ship's noise generator was energized in the review room to establish an 80-db acoustic noise level approximately 30 ft from the program speakers. The acoustic noise level of 80 db is not an uncommon noise level aboard Navy vessels.

Feature films were then reproduced, with the distracting noises previously described, and their intelligibility determined.

We found, by actual experience, that the degree of compression which did not completely destroy the sense of realism was limited. However, we have come to the conclusion that a real improvement in overall sound intelligibility, without destroying the artistic value of the film, or increasing the print sound distortion, could be realized by raising the low-level dialogue sequences 6 db. Peak levels as well could be raised 3 db without difficulty.

This, then, is an attainable improvement in the dynamic range of release prints.

We are presently using the industry averages shown in Table III in evaluating the acceptability of prints for Navy use. (It is our intent to eliminate from

Table I. Dynamic Ranges in Release Prints

Producer, date and total no. of releases	No. B&W V-A	Peak, db		No. B&W V-D	Peak, db		No. C V-A	Peak, db		No. C V-D	Peak, db	
		Max.	Avg.		Max.	Avg.		Max.	Avg.		Max.	Avg.
A, 3-15-51 – 9-11-51(21)	(5)	−4	−10	(11)	−7	−13.4	—	—	—	(5)	−9.9	−18
B, 3-19-51 – 9-14-51(35)	(27)	−6	−14	(2)	−5	−11	(6)	−9	−17	—	—	—
C, 3-15-51 – 9-10-51(29)	(8)	−7	−13.5	(9)	−9	−16	(10)	−8	−15	(2)	−5	−12
D, 5- 4-51 – 9-13-51(11)	(8)	−6	−14	(3)	−7	−12	—	—	—	—	—	—
E, 3-20-51 – 9-13-51(27)	(12)	−2.8	−9.8	—	—	—	(15)	−12	−21	—	—	—
F, 3-30-51 – 8-30-51(18)	(14)	−6	−13	—	—	—	(4)	−8.5	−15	—	—	—
G, 3-23-51 – 9- 7-51(30)	(16)	−4	−11	(6)	−10	−18	(8)	−8	−15	—	—	—
H, 3-19-51 – 9-11-51(9)	(9)	−5.7	−6.4	—	—	—	—	—	—	—	—	—
I, 3-20-51 – 9-13-51(28)	—	—	—	(12)	−6.8	−12.9	(16)	−7.8	−15	—	—	—
J, 4- 2-51 – 9-13-51(7)	—	—	—	(7)	−8.6	−18.8	—	—	—	—	—	—
K, 3-20-51 – 9-10-51(16)	(16)	−4.7	−10.9	—	—	—	—	—	—	—	—	—
L, 3-29-51 – 4-24-51(4)	(2)	−6.9	−16.5	(2)	−15.1	−20	—	—	—	—	—	—
M, 6-14-51 – 9-10-51(5)	(2)	−6.5	−13	(3)	−7	−11.5	—	—	—	—	—	—

Table I

Key: Producers identified as A – M; number of prints given in parentheses; B&W V-A, black-and-white variable area; B&W V-D, black-and-white variable-density; C V-A, color variable-area; C V-D, color variable density.

Navy distribution the worst examples given on the "extreme quality" figures [Table IV] since there is obviously no possibility of manufacturing a projector to reproduce these low-level prints satisfactorily, and if there was, the signal-to-noise level of such a print would render it valueless.)

It is significant, as pointed out at the beginning, that there are many users of 16mm copies of 35mm entertainment films. It is notable that in Class "A" releases in 35mm some 350 prints will be made for commercial exhibition. Every care and consideration is given to the making of such 35mm prints since the audience to which they are to be shown represents the major source of revenue to the industry. In order to insure and protect this source of revenue, the prints must in all respects be heralds of the art of the motion picture. Nothing is permitted which would detract from that art.

There is no disputing the soundness of the precautions taken to prevent release of inferior 35mm prints. In fact, the engineer has been successful not only in improving and enhancing the input into the sound and motion picture camera, but he has also translated the sound and image, through processing techniques, into 35mm release prints which are truly symbols of the art of the motion picture.

Why has this same effort not been made in the direction of 16mm release prints? Certainly the same factor of inviting audience appreciation is present. The Navy and the other Armed Forces do represent a large segment of the motion picture viewing population. From that standpoint alone, we are

Table II. SMPTE Test Film, Black-and-White Print.

	Max. level	Avg.
Dialogue test (sound excellent)	−6 db	−10½ db
Piano test (sound excellent)	−6	− 8
Orchestra (sound excellent)	−2	− 8
Opening music	−2	− 8

Table III. Overall Average of Data in Table I, for Total of 240 Prints and Releases Over Period From 3-15-51 to 9-14-51.

Type of track	No. of prints	Max. peak	Avg. peak
Black-and-white, variable-area	119	−6 db	−12 db
Black-and-white, variable-density	55	−8	−14
Color, variable-area	59	−9	−16
Color, variable-density	7	−7	−14

Table IV. Volume-Level Extremes.

	Best Film			Worst Film		
	Pro-	Peak, db		Pro-	Peak, db	
Type of track	ducer	Max.	Avg.	ducer	Max.	Avg.
Black-and-white, variable-area	E	−0	− 4	D	−14	−20
Black-and-white, variable-density	A	−3	− 6	A	−14	−26
Color, variable-area	G, I	−2	−10	G	−16	−26
Color, variable-density	C	−4	−10	A	−20	−30

sure that you will agree that the deprecation of the "Art" in the form of poor sound and picture 16mm release prints is undesirable.

This, then, is not only our problem, but more largely it is the problem of the motion picture producer and engineer in turning out a 16mm release print that can, as far as practicable, herald the art of the motion picture to the extent that the current 35mm print is symbolic of that art.

Discussion

John Hilliard: I'd like to ask Lloyd Goldsmith, Joe Aiken, Samuel Cohen, Norwood Simmons, Fred Albin, Art Blaney and Eddie Reichard, if he's here, to come up and be available for questioning in this period.

We will proceed with a direct question-and-answer period so that the Navy can have available information which they specifically came out here for.

The first question that they are interested in, perhaps, will be a brief review of optical reduction from 35 to 16, and if Sam is not here, Eddie would you come up and briefly review for us the process that you use in connection with optical reduction of 35mm prints to 16? Tell Mr. Cowett and Mr. Orr the process involved in both black-and-white and color. I see Mr. Cohen is here. Sam, we've asked that you review for us briefly the optical reduction technique that you use in your laboratory to produce the 16mm prints similar to those used by the Navy. In other words, explain what the technique is in connection with both variable-area and variable-density.

Sam Cohen: Is this with regard to sound track and picture?

Mr. Hilliard: Both, but principally in connection with sound track because they are having difficulties in evaluating problems in connection with variable-area and variable-density — something that Mr. Cowett can elaborate on as we go along.

Mr. Cohen: I may be taking a bad step here: but in every case we recommend re-recording the sound negative and not making dupe negatives from the 35 material. Dupe negatives made from the 35 material do not give nearly the quality obtained when a 32–35 track is recorded with 16mm characteristics.

Mr. Hilliard: They are unfamiliar with the technique of optical reduction from 35 to 16 and could you inform them?

Mr. Cohen: In optical reduction there are various machines that reduce the 35mm to a dupe negative 0.8 in width and 0.4 in length. To take area as one specific case, we take the 35mm fine-grain which is made to a density of 1.90 to get a slightly filled 35mm fine-grain track. This is reduced to a sound-recording stock and is exposed to reach proper density by developing in a high-contrast developer. We obtain a negative density slightly lower than an original recorded negative. That is, an original recorded RCA negative would be a density of 2.75 and a dupe negative would be 2.5 on sound-recording stock developed in high-contrast developer, optically reduced 0.4 in length, 0.8 in width, and this gives a variable-area 16mm negative from which your reprints can be made. On variable-density, this can be done either on a positive or negative stock. We have achieved better results by duping to a panchromatic stock and developing it in a negative developer of low contrast. Panchromatic stocks developed to a gamma of 0.55 will closely reproduce the original bias and unbias densities

Mr. Hilliard: In your judgment, is there any difference between the development for variable-area and variable-density that would reflect a change in quality for the 16mm work aboard ship.

Mr. Cohen: If they are not developed in the proper developers there will be a definite loss. In variable-area, for instance, many times laboratories try to make composite dupe negatives from variable-area material and naturally they're miles apart because the picture dupe should be developed to a gamma of 0.55 on a low-gradation stock, where the sound should be developed to 3.00 plus gamma on a high-contrast stock. So if you try to make a composite or a single variable-area dupe and develop it in negative-action developer, the results would be atrocious and the same goes with variable-density. If you try to put that on a high-contrast stock and develop it in a high-contrast developer, you would have bias – unbias going from 0.30 to 1.30 or thereabouts. You couldn't compensate in printing.

Mr. Hilliard: There has been indicated some difficulty with variable-density as compared to variable-area and I would like to have Mr. Cowett make a few remarks along that line to see if we can help him in that connection.

Philip Cowett: Every report that we have received from the field, from many ships out in various parts of the world, indicates that variable-density is the one source of headache and all ask, "Can all of our prints have variable-area sound tracks?"

Mr. Cohen: Are those prints you're talking about or dupe negatives? I don't understand. Do you want the release prints to be on variable-area track?

Mr. Cowett: Yes.

Mr. Cohen: I see. Well, there is a definite reason for that. We run into that a good deal with television stations. A picture recorded for 35mm, either in density or area, does not have the characteristics to give volume necessary in the 16 projector; the density track seems to suffer more; and improper laboratory control can hurt density track much faster than it can hurt area. If it is printed too heavy, volume is lost immediately; and on area, quality is lost more than volume — volume to some extent, but quality is lost much faster than volume.

Mr. Cowett: Is it then possible for the motion picture industry to produce all 16mm prints with variable-area tracks?

Mr. Cohen: No, there are some other factors that enter into it. It is really not necessary if the original material is made properly. We are doing 50% area and

50% density sound at the present time, and from a volume and quality standpoint each is equally good. The Navy should specify a sound track made for 16mm. In many cases I know that just 35mm frequency-characteristic tracks are being used for production.

Mr. Hilliard: That is the reason Mr. Cowett is here. He would like to obtain sufficient information so that he can stipulate what should be the optimum for both types of recording in connection with the 16mm prints that the Navy uses.

Mr. Cohen: Every Navy contract I've come in contact with stipulates certain fine grains and a certain number of prints. None of them that I've heard of has stipulated a sound track recorded for 16mm, which comprises the majority of the prints.

Mr. Cowett: I imagine that, since I am not a film man, Mr. Marks may later have something to say on that, but it would seem to me that since we were getting a 16mm print, the sound track should also be for a 16mm.

Mr. Cohen: But many of the people producing the pictures are in studios where there is no 16mm equipment, where 16mm is done outside and the contract doesn't often call for it, and they show the 35mm print; when they get their approval they ship the 35 to get the approval, and it's run in the 35 projection room, and it stands to reason that if they want that to be the best, they can obtain it, in order to sell more pictures, which is reasonable.

Mr. Cowett: We used to view the 35mm prints for acceptance and then wouldn't bother too much looking at the 16. But now we run off each print and each print is rejected if it's not good.

Mr. Hilliard: I'd like to ask Joe Aiken what experience he's had in connection with their work at the Navy laboratory, in connection with variable-area and variable-density. What do you think are the difficulties involved here with Mr. Cowett?

Joe Aiken: We have had very little comparative experience between 16mm variable-area and variable-density prints at the Naval Photographic Center, as our prints have all been variable-area for the past several years. However, since this question of dynamic range and overall level has been presented, I will describe our recording practices to see if there is a parallel with the problem which Mr. Cowett has brought up.

The Naval Photographic Center produces Navy training films primarily. Dr. Carpenter has discussed certain phases of them at this Convention. We produce a part of the training-film program; the majority are produced under contract by commercial studios and under Navy technical supervision. In many of them, sound effects and music are employed in much the same manner as in entertainment films. Usually training films are produced first in 35mm. Following their acceptance, those produced at the Photo Center are re-recorded to 16mm for release printing, with a frequency characteristic slightly restricted at both ends of the spectrum, and keeping the average recorded level as high as practical. When the ratios of levels of voice, music and effects are established in mixing for the 35mm sound track, we keep 16mm reproduction in mind. We therefore hold the dynamic range within closer limits, with less spread between highest and lowest levels, than is customary in 35mm entertainment films. Although extremely low voice passages are not permitted, the films are quite acceptable in their 35mm versions.

Mr. Cowett has stated elsewhere that the difficulties described in his paper have not been experienced in projecting 16mm prints of Navy training films. It is my personal opinion that those studios that wish to produce both entertainment films for 35mm theater release, and 16mm prints for projection under less desirable conditions, could afford to consider the use of two techniques when voice, music and sound effects are mixed. One mixing technique is suitable for the 35mm theaters, and the other, for 16mm projection, which confines the dynamic range within closer limits, and where important voice passages are maintained at adequate levels.

Mr. Cohen: On that, here, we do all the re-recording right from the first trial print of the 35mm in order to avoid the expense of a complete re-recording job which would be quite an expensive operation

and the results are, the sound men think, quite satisfactory, without going to the original of a new dub job. It's considerably less.

Mr. Hilliard: Sam, would you briefly indicate your experience in connection with this color problem, that is the Navy's problem of large variations in volume with the difference in type of dye tracks.

Mr. Cohen: Every color process that's going through today requires a different track treatment. Certain dye tracks are being sulfided or subjected to various other treatments to enable them to be used with their present exciter lamps. Present systems haven't run into any difficulty except where the track hasn't had enough volume in the original recording. It does require a greater amount of volume than on a black-and-white track; and if the track has just been recorded for black-and-white, then is being used in a color process, it will not be completely satisfactory; and if different processes are used — such as for Technicolor — and the same product used on another process, the results would not be of equal quality.

Mr. Hilliard: Mr. Cowett indicated informally in a sound session yesterday that the green-dyed sound track on the lead sulfide cell gave little or no output.

Mr. Cohen: I don't think that the color, whether it's green or brown or black, has as much to do with it as the opaqueness or the transmission of the track itself.

Mr. Hilliard: Well, that is really the factor that we're involved in — the lead sulfide cell and the green color. You know the lead sulfide cell is most sensitive in the infrared region.

Mr. Cohen: In going through track problems, we use various types of track application and various processes in our laboratory. When viewing the tracks and listening to them you can have a different color, as some tracks go from the yellow to a dark brown in color and still retain the same amount of volume, if all of the image is there and if there is proper transmission density. But as for the green, we have used a track that does have a green color and in theatrical production the volume has been sufficient, but that volume was recorded there originally. By the way, the majority of the time we use a variable-area track, in which you can naturally get quite a volume if you go to 100% modulation, although I believe (in present theater practice) it runs around 40% modulation. You can increase that volume tremendously.

Mr. Hilliard: I'd like to direct a question to Dr. Frayne in connection with photocells that might be available to help reduce the variation with color. Is there any comment that you can make at this time?

John Frayne: Before I answer your question, I think I should clear up further some of what Sammy Cohen has been covering: for example, you lose sound level on a track if the photocell sees it as practically a transparency. It's not necessarily a matter of opacity; the track *may* be too transparent in some cases. For example, some of the dye tracks which may have a visual density of around 2.0 in the case of variable-area, to a photocell with a cesium surface they may appear to be as low as 0.2. In that case, of course, you lose all the contrast in the track and therefore lose volume. It is well known that the Bell Telephone Laboratories are actively engaged in the phototransistor development which may or may not have application to sound systems. There are none yet available commercially, but they would seem to be a very natural device for the sound picture business.

Mr. Hilliard: You had a question in connection with contracts?

Mr. Marks: Mr. Cohen, you mention that you are willing to supply something so long as the Navy would tell you what to supply, that since the Navy contracts didn't mention anything about 16mm print specifications, you therefore had free choice in supplying the type of prints that you did supply.

Mr. Cohen: No, there's one error. I work for a laboratory, not for a producing company, and it's the producing company that has the contract; it's the producing company that delivers to the laboratory. We are not in the sound recording business so we process whichever films the producer delivers to us. We don't tell the producer what he is to produce.

Mr. Marks: I'm not taking issue with you, but you implied that you had Navy

contracts. You had producers' contracts.

Mr. Cohen: No, I don't have Navy contracts. I said that we do work for people who have Navy contracts and they bring in certain materials and I'm telling you from practical experience just what material comes in. I am in a position to see what comes into the laboratory, probably in a very good position to tell what type of material is going out, but it is the Navy's responsibility directly to write the contracts.

Mr. Marks: You deal as a subcontractor with the Navy, you don't have anything to do with the Navy contract itself.

Mr. Cohen: No, none whatever.

Mr. Marks: So, therefore, you couldn't say that we do not specify any particular treatment in the contract.

Mr. Cohen: Well, we have to deliver all the material to the Navy. If the contract calls for a fine grain and two 35mm prints and five reduction prints, as a number of them are coming through, that material goes. We would not be making the 16mm prints from a 35mm original negative if there was a 16mm negative recorded.

Mr. Marks: Well, I agree in that respect. But the matter of fact is that the Navy does not specify the type of 16mm release prints or sound track for a very tangible reason, for the same reason that this study was made — because there was no experience with it until very recently. Now we intend to apply the results of this study.

Mr. Cohen: That is what I'm trying to bring out here. I'm not finding fault with the Navy. I'm trying to help the Navy. I'm telling you what should be put into the contract in order to get a result, so that on board ship they would have prints with volume.

Mr. Marks: We are not prepared to insert anything into the contracts based on this study alone. That is why we are inviting the study of the Society of Motion Picture and Television Engineers in order to help us arrive at a specification which is practicable, both from our standpoint and from the capacity of the industry to produce. We don't want anything unreasonable from the companies. However, from a contractual standpoint, every time an order is placed, regardless of whether the type of film is specified, there is an implied liability upon the part of the producers to supply a product which is fit for the use intended. We maintain that at the present time nothing is being supplied, except in rare cases, which is ultimately fit for the use intended, soundwise, when compared with the Society's 400-cycle test film. Along with that, every producer has been charged with the knowledge that we are using this JAN 16mm projector.

Mr. Cohen: If all this were true, there would be no problem.

Mr. Marks: Well, I agree and that's why we're bringing it to the attention of you people, in order to help us to help ourselves. And I think, personally, it should be a matter of pride with the entire industry to attempt to produce a print which will have the same artistic impact that it has on the general public in the form of a 35mm print.

Loren L. Ryder: In the discussion that is taking place a quality comparison has been made between reproduction of area and density 16mm sound films. During these discussions no mention has been made of supersonic direct-positive prints of the density type. Direct-positive supersonic density prints on 16mm film when reproduced on proper equipment are comparable to 35mm optical prints. If a decision is made, it should be made after a study of what may be done and not based solely on past practices.

Lloyd Goldsmith: I think Mr. Cowett's paper as read today is a most timely one. As I see it, speaking from the sound-quality standpoint, the basic problem, as also stated by Mr. Cohen, is to get a re-recorded release 16mm negative. That is the first step. In the process of making that negative from previously recorded 35mm materials, the volume range must be restricted over that normally employed in 35mm recording. That is the second step, and it was very well brought out in Mr. Cowett's paper. The third step, if necessary, is to make a correction in the frequency response over that originally employed in the 35mm material. All of this is not new. It has been known

certainly since the experience we had in the last war in securing from the motion picture industry improved 16mm prints for use by the armed forces. Speaking for Warner Brothers, at least, in 1943 we were convinced that a separate release negative for 16mm was desirable and we have been making such a negative from that time.

I might mention that in making the 16mm release negative from original 35mm material, in re-recording, we do not, at Warners, change the frequency response very much. However, that is largely due to the fact that the 35mm material released for showing in theaters has a frequency range, speaking now for music, with a low end around 60 cycles, no intentional cutoff, and a high end around 6000 cycles, with an intentional sharp cutoff filter of 6700 cycles. In the case of dialogue the original material is re-recorded with the same upper-end limitation, flat to 6000, but the low end is cut off as sharply as possible at 100 cycles. In re-recording this material from 35 to 16, to make a new release negative for 16, we make no change in the frequency response. This we feel is predicated on good release printers which give good contact and will faithfully reproduce the high frequencies, whatever there are, to 6000 cycles.

The one thing we do, however, in preparing this release negative, is to restrict the volume range. We intentionally pull up the low-level dialogue passages from 4 to 6 db. As indicated in Mr. Cowett's paper, it would appear that the desirable added amount of compression would be something in that range. I might add that our original material is fairly well compressed in the 35, so we feel that an additional 4- to 6-db pull-up for 16 release is satisfactory. To help the re-recording mixers accomplish this, we force them to re-record with the gain in the mixer monitor's horn circuit reduced from 4 to 6 db. Therefore, he has to pull up the low-level dialogue from 4 to 6 db for a corresponding intelligibility which he has been used to. The high-level passages, particularly the main and end titles, in music, that are normally 100% modulated, he still holds to 100% modulation by means of peak-reading volume indicators, as it is recognized that there must be no intentional overloads in the 16mm release material, unless it be of certain sound effects which can stand such overloads without apparent distortion.

I would like to stress again those three steps: the special re-recorded release negative, compression of volume range, and restriction of frequency characteristic if necessary. That is the secret of good 16mm release sound quality from 35mm original material.

Mr. Cowett: I should like to thank the members of the motion picture industry who appeared here on this panel and hope that some day the entire industry may follow the process outlined by Mr. Goldsmith which appears to be a workable and a desirable plan.

High-Speed Motion Picture Cameras From France

By PAUL M. GUNZBOURG

Two high-speed motion picture cameras developed by the French firm of Merlin-Gerin-Debuit are briefly described. The first operates at a speed of 3000 frame/sec, using 100-ft rolls of 16mm film; the second, using standard 35mm film, can be operated up to a speed of 100,000 frame/second. Both cameras employ a rotating lens drum. In the slower camera ordinary oscillographic film unwinds continuously by conventional means. The second camera uses the device of a film strip which is attached to the interior of the lens drum rotating with it.

3000 Frame/Sec Camera

The optical principle of the camera, shown in Fig. 1, is based on the juxtaposition of a stationary objective and a series of mobile objectives passing rapidly before it. For the mobile objectives-compensators, commercial lenses with $\pm 1\%$ tolerances are used.

A primary objective with a focal length of 140 mm, housed in a focusing mount, is capable of focusing at distances ranging from 4 ft to infinity. For distances from 2.5 in. to 4 ft, other objectives of 50-mm (2-in.), 80-mm (3.5-in.), 100-mm (4-in.) and 120-mm (5-in.) focal length can be substituted in similar mounts.

Optical compensation is provided by a rotating drum with 80 small objectives set at equal distances around its periphery. These are three-element anastigmats with a focal length of 20 mm at an aperture of $f/3.5$. Figure 2 shows the optical drum.

The film is driven by a double row of sprocket teeth in the lens drum and passes in the conventional way from the supply to the take-up spools. The drum is made in one piece and, in rotation, controls the movement of both film and lenses. This principle provides for synchronization of both film and images without mechanical means. Undue tension of the film is avoided by having 6 to 8 teeth of the lens drum in mesh, resulting in movement of the film without tear or breakage. Power is supplied by a universal a-c and d-c 110-v or 220-v motor of high-starting torque, developing about 20 hp at starting.

A synchronizing device, operated by an adjustable electrical contact, per-

Presented on April 6, 1949, at the Society's Convention at New York, N.Y., by Paul M. Gunzbourg, Mac Donald International, Inc., 115 Broadway, New York 6, N.Y.

Fig. 1. Interior view of 3000 frame/sec camera.

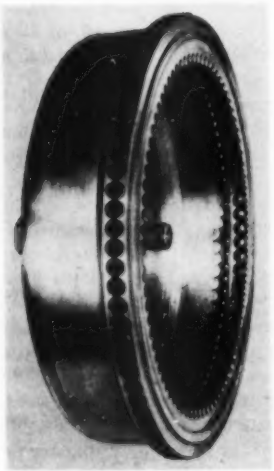


Fig. 2. Optical drum of 3000 frame/sec camera.

mits the camera circuit to be closed or opened in accordance with the length of film desired to be exposed. Since the current draw is about 0.5 amp, a contactor relay is necessary for the starting and stopping of the motor. This device may be adjusted according to the synchronization requirements of the phenomenon being photographed or to the length of film in the camera.

A set of changeable slits of various widths is provided with the camera. These slits, fitted between the fixed objective and the mobile objectives on the lens drum, permit the decrease of the exposure time per frame at a given frame frequency by a ratio of 1:4. A centrifugal brake with which the motor spindle is equipped permits the adjustment of the speed within the range of ±10%. This adjustment can be ap-

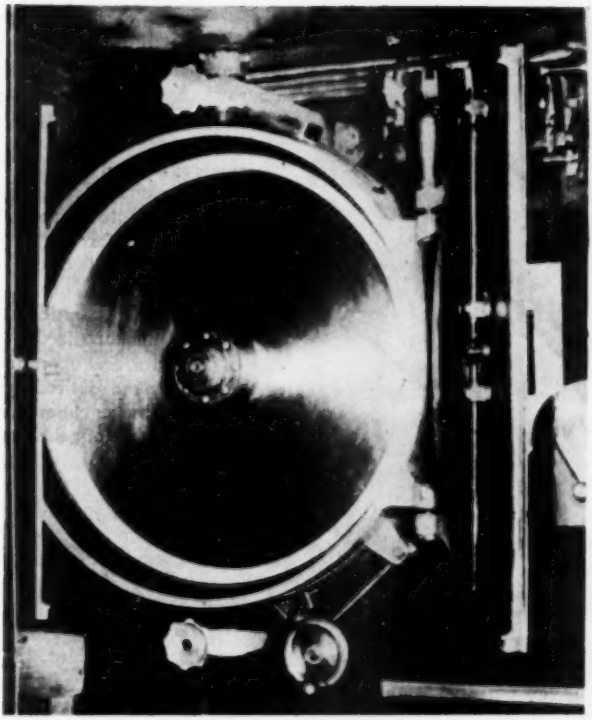


Fig. 3. Interior view of 100,000 frame/sec camera.

plied from the moment when 10–12 m (33–40 ft) of film have been unwound.

Accessories of the camera consist of a reinforced braced tripod and a focusing microscope to be attached to the viewfinder. The camera itself weighs about 16½ lb without motor and accessories, and can be easily handled.

100,000 Frame/Sec Camera

The same principle of optical compensation is used in the 100,000 frame/sec as in the 3000 frame/sec camera. The basic difference in the design of the two cameras lies in the device adopted in the faster camera to allow for movement of the film at the far higher rate of speed required.

Since no film could withstand being driven at such high speed by any of the conventional film drives, the film in this case is applied directly against the inner surface of a rotating drum, 0.605 m in diameter, and can thus be rotated with it at the required speed of 250 m/sec (820 ft/sec) without damage. The length of film that can be used is, of course, determined by the circumference of the inner surface of the drum wall, which measures 1.90 m (74.8 in.). One revolution of the drum results in 750 pictures, representing a 50-sec projection at normal speed when the frames are placed in sequence. For example, with the drum rotating at 6000 rpm (film velocity 190 m/sec) the frame frequency resulting is 75,000/sec for a total duration of 0.01 sec.

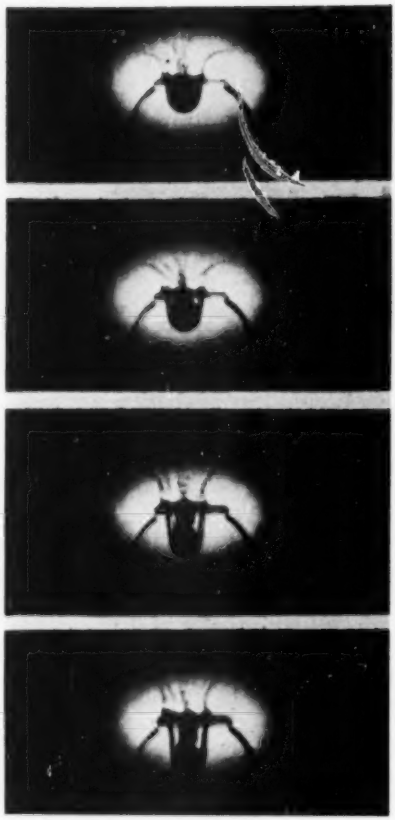


Fig. 4. Billiard ball falling into glass of water. Speed: 2500 frame/sec.

The optical drum carries on its periphery 750 fixed compensator objectives, arranged in three rows, of 250 lenses each, parallel to the drum axis. Each row is staggered one-third of the level of the adjacent row below it. One lens from each row is uncovered in turn, a slit being used to limit the angle and the exposure duration per frame. The objectives are three-element anastigmats with 20-mm focal length and $f/3.5$ aperture. The film is held taut on the inner surface of the drum against the objectives, by a flexible bronze strip applied on the reverse side of the film acting as a rear pressure plate. An interior view of this camera is shown in Fig. 3.

As the drum rotates, the compensator objectives pass before a fixed objective having a diameter of 70 mm and a focal length of 350 mm. The fixed objective is fitted with an automatic magnetic capping shutter, synchronized with the motion of the drum, and operating when the drum reaches the desired speed of rotation. The shutter closes after one complete revolution of the drum. The length of film in the camera is thus fully utilized.

The sequential images produced in this camera are presented as three circular images, each 6.5 mm in diameter, lying obliquely across the film, with frame 1 produced by a lens in row 1, frame 2, by the next lens to be uncovered in row 2, and the third, by the corresponding lens in row 3. For projection purposes, the images are optically printed, approximately three times enlarged, onto standard 35mm film, as shown in Figs. 4 to 7. Lighting sources used in the examples shown here were either flashes of $3\frac{1}{2}$ oz of magnesium set off behind ground glass, or two projection-light sources with parabolic reflectors fitted with 2-kw bulbs, also behind ground glass.

Power is provided by a compound 150-v, d-c motor requiring about 0.5 hp. Viewing is through a shutter-equipped window. Other features inside the housing include contactor and push-button devices for starting and stopping the driving motor, and for unwinding and developing the film automatically. The camera weighs approximately one ton.

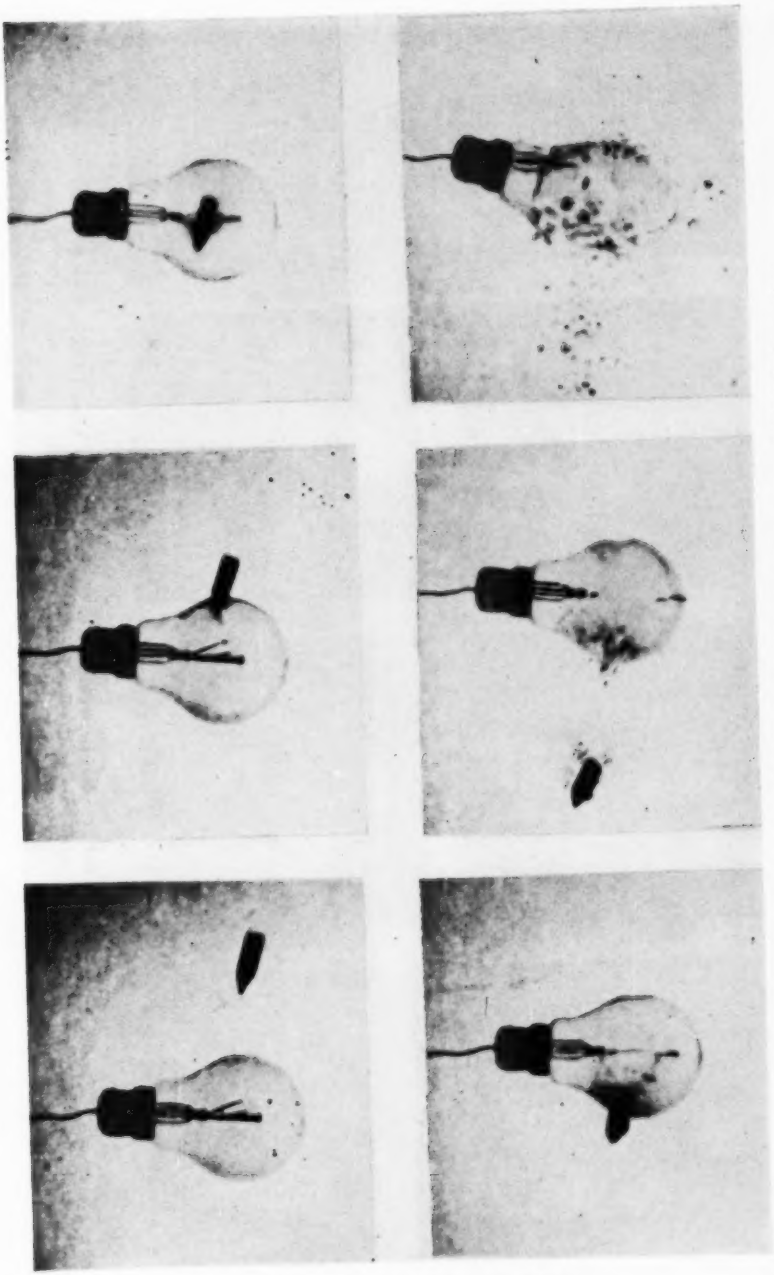


Fig. 5. Perforation of electric light bulb by bullet. Speed: 75,000 frame/sec.

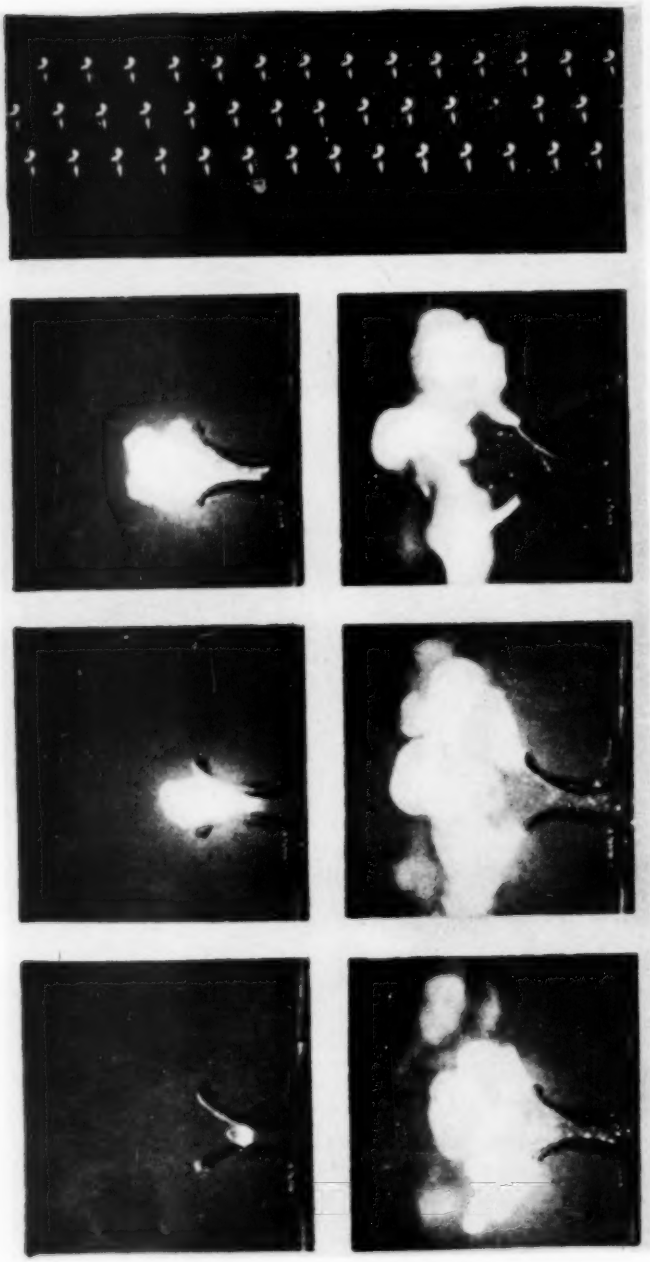


Fig. 6. Electric arc (d-c) between two electrodes. Right: exposed film, reduced one-third. Speed: 75000 frame/sec.

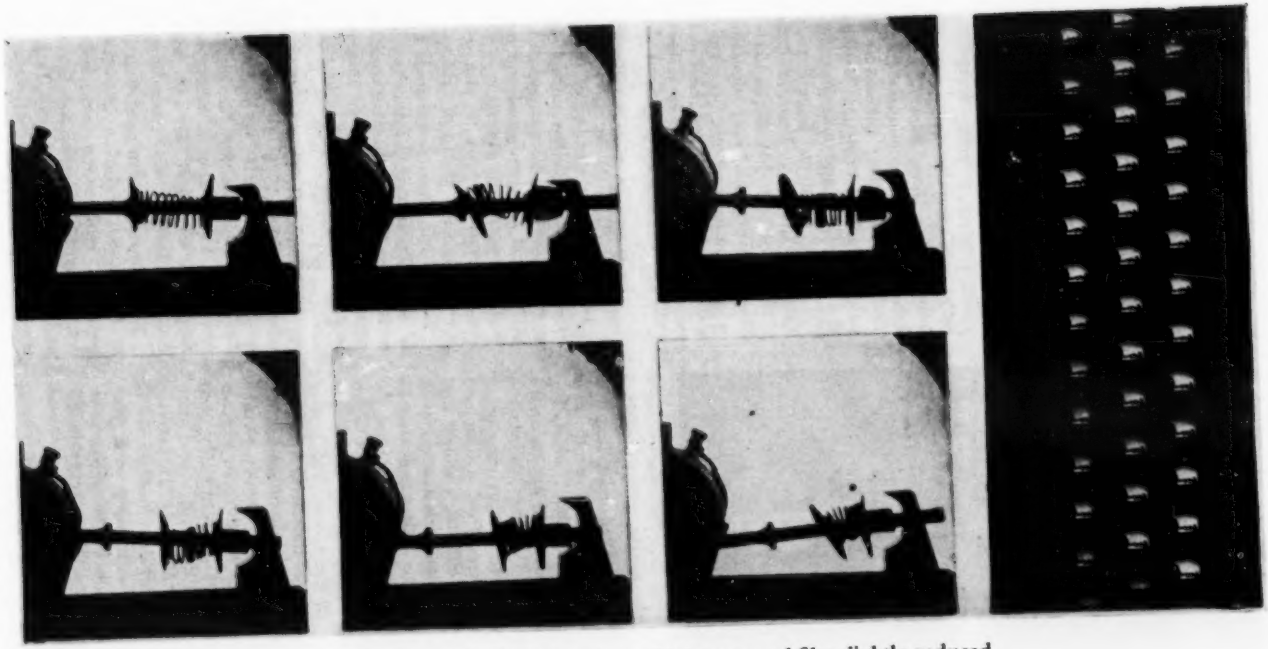


Fig. 7. Spring strained to distortion. Right: exposed film slightly reduced.
Speed: 75,000 frame/sec.

Biographical Note

A. C. Downes

"Arthur C. Downes, Chairman, Board of Editors" has been appearing month after month for 11 years in this *Journal:* no more propitious words could appear on the *Journal's* masthead.

We do not apologize for thus introducing a man who has retired from a long and successful career as chemist, engineer and research leader. Those who have known him over some years will agree that in speaking of him it is in order to treat the immediate immediately — while not slighting what is more distant.

The quality of the recent Volumes of this *Journal* has been the direct result of a great deal of constant attention by Mr. Downes, who reviews every paper, assesses the evaluations made by those he chooses from the Board of Editors to study each paper, and prepares the verdicts and often extensive advice for authors. This service is not a casual part-time hobby. It is a job of carefully winnowing each year at least a couple of solid bushels of papers — to find some completely acceptable for publication, some satisfactory in part and others which must be rejected. The Chairman of the Society's Board of Editors is responsible for assessing them all.

(We should note here that these extensive activities of the Chairman of the Board of Editors for today's *Journal* are made possible by efficient secretarial service given by the staff of National Carbon.)

Arthur Caldwell Downes was born in Ipswich, Mass., in 1882. (This and a few other milestones are here recorded, chiefly from *American Men of Science*, 8th ed., 1949): B.S. from Massachusetts Institute of Technology in 1904; chemist at Hartford Laboratory Co., 1904–05; National Carbon Co., Cleveland and Fostoria, Ohio, 1905–17; Assistant Superintendent of National Carbon's Fostoria Works in 1918–21, Cleveland Works in 1921–22 and Niagara Works in 1922; directing work on illuminating carbons, electrical brushes and new carbon products, he was head of the Works Laboratories in Cleveland in 1922–25 and the Development and Research Laboratory from 1925 until his retirement in 1947.

He has been a member of this Society since 1927 and a Fellow since 1934. He served as Editorial Vice-President in years very critical for the *Journal* and for Conventions and Papers Programs — 1941–46. During these six years he also served as Chairman of the Board of Editors.

In 1947 Mr. Downes was made a Fellow of the Illuminating Engineering Society which then cited his 40 years as an illuminating engineer, his IES committee work and his many contributions to *IES Transactions*, principally with reference to spectral characteristics of sunshine and its substitutes. In 1928 he received the award of the Academy of Motion Picture Arts and Sciences for his illumination research. He is also a member of the American Chemical Society and the American Institute of Chemical Engineers.

A. C. Downes did a good deal of work in Hollywood beginning in 1935 when high-level illumination was being developed by Mole-Richardson Co. for the studios to use with the new Technicolor process. It is, some think, farther than

the map shows from Arthur Downes' birthplace in Ipswich, Mass., to Hollywood. In between, it is true, is Cleveland, where one of his associates reports, "He has always been known simply as 'A. C.' and his long-time and expert knowledge of carbon formation procedures and of the light-emitting properties of illuminating carbons has been continually respected and put to good use by his co-workers."

Though long known as A. C., he is also known as one who uses direct current methods to get things done — forthrightly, efficiently and with understanding. And this is how he got on in Hollywood, according to a note from Elmer Richardson:

"Here in Hollywood we probably go overboard with our informality. No one works in the Hollywood technical group long before he is better known by his first name than his surname. Right from the start among ourselves, we always referred to A. C. Downes as Arthur, but at first we did not want to offend him so we all stuck with 'Mr.' One day when we were all together, some one said: 'Let's have some fun,' so Pete (Peter Mole) was nominated to start addressing our good friend, Mr. Downes, as 'Arthur'; and so Pete, in his quiet way, with a twinkle in his eye 'broke the ice.' I think Arthur was a bit flabbergasted at first but after he got accustomed to it, I think he was as happy as we were to drop the 'Mr.'

"Arthur Downes to me is a friend, a man with that combination of intelligence, experience and knowledge that is best defined as wisdom, and with human qualities that make cooperation with him a delight to all concerned."

71st Semiannual Convention

The Advance Notice listing the sessions and abbreviated titles of papers went to members in the Western Hemisphere on March 10. That was the mailer which includes the tear-off postal card for conveniently arranging hotel accommodations at The Drake in Chicago during the Convention. If you have mislaid yours, please refer to p. 173 of the February *Journal*, which has the information you need.

Here is the schedule of 11 sessions in which Program Chairman George Colburn had some 52 papers arranged at press time:

April 21–25

Monday afternoon and evening
Television

Tuesday morning
Screens and control of brightness

Tuesday afternoon
Armed Forces production

Tuesday evening
Magnetic projection; Film inspecting; Future use of educational film

Wednesday morning and afternoon
High-speed photography

Thursday morning
Open

Thursday afternoon
Color; Laboratory

Thursday evening
General Session

Friday morning
Sound and editing

Friday afternoon
New equipments

There will be demonstrations of equipment, guaranteeing lively and concrete interest, and we can be sure that Bill Kunzmann's arrangements are auspicious for the Get-Together Luncheon, the Cocktail Hour and the 71st Semiannual Banquet and Dance.

Bill and all the Chicago folks responsible for making the many Convention wheels turn are meeting in Chicago on March 13 for a planning session for which all the signs are good. The roster of chairmen, which was completed at an early date, was published in the February *Journal*.

Book Reviews

The Television Program
Its Writing, Direction and Production
By Edward Stasheff and Rudy Bretz. Published (1951) by A. A. Wyn, 23 W. 47 St., New York 19. 355 pp. incl. glossary and index. Numerous illus. and examples. 6 × 9 in. Price $4.95.

The Television Program is probably the most complete study of television production practices and techniques to date. It should be recommended for a thorough reading by everyone in television and the connected industries, either as a means of reviewing and comparing techniques or as a method of exploring the nature of the new medium.

The authors bring a solid background of actual experience to their work. Edward Stasheff has been in the industry since 1945, serving as educational consultant to CBS, assistant program manager to Station WPIX and as a teacher at Columbia and Michigan Universities. The television record of Rudy Bretz is even longer, including work as a cameraman, as a teacher and as program manager of WPIX.

For easy assimilation, the book is divided into four parts: (1) the nature of the television program, (2) the writing of the program, (3) the writing of the fully scripted show, and (4) the producing and directing of television.

Part One analyzes the television program and points up the differences between it and other media. Television production units are described, with the authors realistically bringing out the limitations imposed by budgets, time and space. Types of television shows are listed and described by formats and finally the reader is given a cursory run-down of the basic shots and visual transitions currently used in television.

Two sections are devoted to writing the television show. Of particular interest to engineers would be sections 12 and 14, respectively, "Technicalities of Writing for the TV Camera" and "Transitional Devices."

Part Four, "Producing and Directing the Television Program," has the ring of authenticity that comes from personal experience. Not only are the functions of the producer-director set forth, but the spirit motivating the production art is nicely translated into words. Television aspirants looking for a "bible" of the television production art, complete to the current moment of publication, can find it here in Part Four.

It should be especially noted that each section of the book is illustrated with charts, diagrams and reproduced "air" scripts, the latter embellished with photographs of the action as it would be seen by the television camera.

Next to actual experience and observation, research is an effective way to learn television production. For those interested in using this method, *The Television Program* will be found invaluable.—*Dik Darley*, Director, American Broadcasting Company, ABC Television Center, Hollywood 27, Calif.

Motion Pictures, 1912–1939

A catalog compiled by the Library of Congress. Published (1952) by the Copyright Office, Library of Congress, Washington 25, D.C. 1256 pp. Bound in buckram. Price $18.00.

The press release of the Library of Congress describes this as a monumental catalog that lists more than 50,000 motion pictures registered in the Copyright Office from 1912 through 1939 and notes that the catalog contains much information that has hitherto been available only after prolonged research in the files of the Copyright Office. The release also contains the information which follows.

As time passes and old producing companies and their films are forgotten, this volume will become increasingly valuable as a reference book on films and film history. The information given about each film includes, insofar as possible, the title, date, producing company, sponsor, information about the published work on which the film was based, physical description, credits, claimant and date of copyright, and the author of the film story. The material for the entries, which are listed alphabetically, was obtained mainly from the record books of the Copyright Office, the original applications for the

registration of the copyright claims, and descriptive material that was supplied at the time the films were registered.

The cumulative catalog has a 268-page index, which lists the individuals and organizations associated with each motion picture, and a "Series List," which provides the name of the copyright claimant and the title and date for each motion picture of a series. Any particular film may be located in a variety of ways—by title, producing company, copyright claimant, alternate title, name of the work on which the film was based, series title, author of the film story, sponsor, and releasing or distributing agents.

Motion Pictures, 1912–1939 is the first publication in the cumulative series of the *Catalog of Copyright Entries*. Work has started on a supplementary volume that will cover motion pictures copyrighted in the years 1940 to 1949. These two cumulative volumes and the subsequent semiannual issues of *Motion Pictures and Filmstrips* in the regular series of the *Catalog of Copyright Entries* will constitute a comprehensive bibliography of United States motion pictures from 1912 to date.

Current Literature

The Editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D.C., or from the New York Public Library, New York, N.Y., at prevailing rates.

American Cinematographer

vol. 32, Nov. 1951

Set Lighting by Remote Control (p. 444) *A. Rowan*

Reflected Light for Color Photography (p. 446) *L. Allen*

Dual-Purpose Projector (p. 450) *R. Lawton*

Planning and Estimating TV Spot Announcement Films (p. 454) *J. H. Battison*

vol. 32, Dec. 1951

Motion Pictures on Tape (p. 500) *F. Foster*

Trick Effects in TV Commercial Films (p. 502) *J. H. Battison*

Audio Engineering

vol. 36, Jan. 1952

The Two Types of Theatre Video (p. 16) *J. W. Sims*

Bild und Ton

vol. 4, Oct. 1951

Zur Messung Fotografischer Zentralverschlüsse (p. 300) *H. Pech*

Die Bewegungskamera und ihre Anwendung (p. 307) *W. Rieger*

Abmessungen für 16-mm-Transportrollen und die 16-mm-Schaltrolle (p. 318) *A. Heine and L. Busch*

British Kinematography

vol. 19, Oct. 1951

The Gevacolor Processes (p. 100) *H. Verkinderen*

The Economics of Film Production (p. 110) *C. Vinten*

Standardization of Projection Lamps (p. 117) *M. Furness*

vol. 19, Nov. 1951

A Photographic Technique for Producing High Quality 16mm Prints (p. 132) *A. Tutchings*

A Method of Making Travelling Mattes Using a Single-Film Camera (p. 139) *G. I. P. Levenson and N. Wells*

A Non-Reflecting Room and Its Uses for Acoustical Measurement (p. 148) *F. H. Brittain*

Electronic Engineering

vol. 23, Dec. 1951

Picture Storage Tubes (p. 472) *R. E. B. Hickman*

Electronics

vol. 24, Dec. 1951

Improving a Film-Camera Chain (p. 103) *C. J. Auditore*

vol. 25, Jan. 1952

Specifications for Color TV Field Tests (p. 126)

Ideal Kinema

vol. 17, Dec. 6, 1951

Third Dimension Demonstration by Means of Sextuple Screen (p. 15 and p. 19)

International Projectionist

vol. 26, Dec. 1951

Movie Studio Carbon Arc Lighting (p. 11) *H. B. Sellwood*

The GPL Simplex Direct-Projection Theatre TV System (p. 22) *F. N. Gillette*

vol. 27, Jan. 1952

DuPont's New "Thin" Film Related to Dacron Fiber (p. 10)

Kollmorgen's New Optics Plant (p. 15)

To Mask or Unmask (p. 16)

Kino-Technik

no. 11, Nov. 1951

Der plastische Film vermag dem Kino neue Impulse zu geben (p. 224)

Störungen bei der Vorführung von Tonfilmen (p. 228)

no. 1, Jan. 1952

Siemens-Projektor 2000 — Ein neues Gerät für die Schmalfilm-Projektion (p. 10) *L. Busch*

Neue Aufnahmetechnik durch das "Travelling Matte"—Verfahren (p. 12)

Störungen bei der Vorführung von Tonfilmen, Pt. 2, (p. 16) *K. Braune and H. Tümmel*

Motion Picture Herald

vol. 186, Jan. 5, 1952

(Better Theaters Section)

How Theatres Can Be Revised for "Full Vision" (p. 8) *B. Schlanger and W. A. Hoffberg*

vol. 186, Feb. 9, 1952

Operation and Maintenance of Theatre TV Equipment, Pt. 6, 35mm Intermediate System (p. 40) *A. Nadell*

Photo-Technik und-Wirtschaft

vol. 2, Nov. 1951

Über die Farbentwicklung im Agfacolor-Negativ/Politiv-Verfahren Reckziegel (p. 446)

RCA Review

vol. 12, Dec. 1951

Fundamental Processes in Charge-Controlled Storage Tubes (p. 702) *B. Kazan and M. Knoll*

Radio and Television News

vol. 47, Jan. 1952

Practical Sound Engineering, Pt. II (p. 66) *H. Tremaine*

(The concluding article of this series detailing how a complete distribution system achieves flexibility by means of patch bays)

Tele-Tech

vol. 10, Nov. 1951

Analysis of Latest Lawrence Color-Tv Tube (p. 38) *J. H. Battison*

Image Iconoscope for Improved TV Film Scanning (p. 44) *R. Theile*

Combined Special Effects Amplifier for Television (p. 50) *W. L. Hurford*

Tele-Vision Engineering

vol. 3, Jan. 1952

Video Studio Techniques (p. 8) *C. D. Parmelee*

New Members

The following members have been added to the Society's rolls since those last published. The designations of grades are the same as those used in the 1950 MEMBERSHIP DIRECTORY, Honorary **(H)** Fellow **(F)** Active **(M)** Associate **(A)** Student **(S)**

Armistead, Mark, President, Mark Armistead, Inc. **Mail:** 1041 N. Formosa Ave., Hollywood 46, Calif. **(M)**

Butler, John W., Executive, Signal Corps Photographic Center. **Mail:** 11 W. Eighth St., New York 11, N.Y. **(M)**

Conway, David L., Director, Photographic and Special Events, WHEN, Meredith-Syracuse Television Co. **Mail:** Maple Hill Farm, R.D. #2, West Monroe, N.Y. **(M)**

De Titta, Arthur A., Pacific Coast Supervisor, Movietonews, 1417 N. Western Ave., Hollywood 27, Calif. **(M)**

Fox, George S., Producer, Designer, Cameraman, George Fox Corp. **Mail:** 6626 Romaine St., Hollywood 38, Calif. **(M)**

Fritzen, John, Technical Services, Cinecolor Corp. **Mail:** 11583 Huston St., North Hollywood, Calif. **(M)**

Gamon, George A., Motion Picture Engineer, Sound Service Co., Pty., Ltd. **Mail:** 6 Alameda St., Parkdale, Melbourne, Australia. **(A)**

Goldberg, Ernest W., President, Golde Manufacturing Co. **Mail:** 1140 Michigan St., Wilmette, Ill. **(M)**

Gonzalez, Jesus G., Recording Engineer, Estudios Tepeyac. **Mail:** Coquimbo 868, V.G.A. Madero, Mexico City, D.F. **(M)**

Goodman, Louis S., Executive Director, Film Research Associates. **Mail:** 150 E. 52 St., New York 22, N.Y. **(M)**

Gordon, Barry O., Instructor, Motion Picture Photography, Ryerson Institute. **Mail:** 42 Roseland Dr., Alderwood, Toronto 14, Ont., Canada. **(M)**

Gromak, Theodore B., Engineer, Motiograph Corp. **Mail:** 409 S. Villa Park Ave., Villa Park, Ill. **(M)**

Hall, Robert E., Motion Picture Film Technician, U.S. Air Force, Wright Field. **Mail:** 359 Hilside Rd., Skyway Park, Fairborn, Ohio. **(A)**

Heininger, Francis, Writer, Director, De Frenes Co. **Mail:** 40 W. Ashmead Pl., N., Philadelphia 44, Pa. **(M)**

Herbst, R. G., Metallurgist, Bell & Howell Co. **Mail:** 9519 Leamington Ave., Skokie, Ill. **(M)**

Hurley, Albert B., Manufacturing Executive, Hurley Screen Co. **Mail:** Huntington Bay Rd., Huntington, N.Y. **(M)**

Karasch, Joseph N., Motion Picture Photographer, Director, United Auto Workers, AFL. **Mail:** 541 Powers St., Port Washington, Wis. **(M)**

Kislingbury, William, Cameraman, Optical Effects, Universal-International. **Mail:** 10423 Cheviot Dr., Los Angeles 64, Calif. **(M)**

Lemmon, Lt. Gene C., U.S. Air Force, Box 0–20, Edwards Air Force Base, Edwards, Calif. **(A)**

MacAllister, Richard, Producer, 16mm. **Mail:** 717 Erie Ave., San Antonio 2, Tex. **(A)**

Maxfield, Harold H., Design, Structural Steel, Canadian Brazilian Services. **Mail:** 241 Torrens Ave., Toronto, Ont., Canada. **(A)**

Miller, James T., Manager, Film Processing, Bry Color Laboratories. **Mail:** 2020 W. Arthur St., Chicago 45. **(A)**

Morrissey, Thomas G., Chief Engineer, Station KFEL. **Mail:** 5700 W. 28 Ave., Denver 14, Colo. **(A)**

Nottorf, Robert W., Chemist, E. I. du Pont de Nemours & Co. **Mail:** Box 175, Parlin, N.J. **(M)**

Ozga, Franciszek, Research, Newman Rudolph Lithographing Co. **Mail:** 1424 N. Damen Ave., Chicago 22. **(M)**

Pew, L. Glen, TV Engineer, KPIX Television, Inc. **Mail:** 13 Ricardo La., Mill Valley, Calif. **(M)**

Poch, Waldemar J., Engineer, Radio Corporation of America. **Mail:** 3 Haines Dr., Moorestown, N.J. **(M)**

Rajagopalan, R., Sound Recordist, c/o Udaya Studios, Alleppey, South India. **(A)**

Ricciardelli, Gino, Assistant Chief Engineer, WNBF-TV. **Mail:** 151 Robinson St., Binghamton, N.Y. **(M)**

Samuelson, Carl, Chemist, Cinecolor Corp. **Mail:** 1136 Green La., La Canada, Calif. **(A)**

Shaw, Robert B., Mechanical Engineer, Off. Sect. of Defense. **Mail:** 8302 Flower Ave., Takoma Park, Md. **(M)**

Sheldon, Eric J., Vice-President, O. W. Ray Corp. **Mail:** 83 Bretton Rd., Yonkers, N.Y. **(M)**

Sobolov, Harold, Instructor, TV Hour Director, American Broadcasting Co. **Mail:** 281 E. 205 St., Bronx 67, N.Y. **(A)**

Stantz, Louveer H., Chief Engineer, WNBF-TV. **Mail:** 168 Moeller St., Binghamton, N.Y. **(M)**

Stimson, Allen, Photometric Engineer, General Electric Co. **Mail:** 40 Federal St., Lynn, Mass. **(M)**

Stinerock, John V., Film Processing Quality Control Engineer, Eastman Kodak Co. **Mail:** 2123 East Ave., Rochester 10, N.Y. **(A)**

Trad, Victor, President, TV Engineer, Trad Television Corp. **Mail:** 82 Almyr Ave., Deal, N.J. **(M)**

Trainer, Merrill A., Manager, Broadcast Equipment Products, Radio Corporation of America, RCA Victor Div., Bldg. 15–5, Camden, N.J. **(M)**

Utlek, Sigmund, Laboratory Technician, Reeves Sound Studios, Inc. **Mail:** 646 Rosedale Ave., New York, N.Y. **(A)**

Woolf, Robert S., Manager, Teletranscription Dept., Du Mont Television Network. **Mail:** 10 Du Pont Ave., White Plains, N.Y. **(M)**

Ziegler, Allison V., Recording Engineer, Westrex Corp., 111 Eighth Ave., New York 11, N.Y. **(M)**

CHANGES IN GRADE

Bashner, Melvin C., (S) to **(A)**
Current, Ira B., (A) to **(M)**
Daniel, George (A) to **(M)**
Dieter, Henry, (A) to **(M)**
Hirschfeld, Gerald J., (A) to **(M)**
Jones, Ronald W., (A) to **(M)**
LaRue, Mervin W., Sr., (A) to **(M)**
Macbeth, Norman, (A) to **(M)**
Ochse, Brand D., (A) to **(M)**
Pessis, Georges, (S) to **(A)**
Rocklin, Ralph J., (A) to **(M)**
Schroeder, Walter A., (A) to **(M)**
Sherry, Frank E., Jr., (A) to **(M)**
Spottiswoode, Raymond J., (A) to **(M)**
Spring, Donald N., (A) to **(M)**
Streech, Wilbur J., (A) to **(M)**
Trentino, Victor, (A) to **(M)**
Youngs, William E., (A) to **(M)**
Von Vollenhoven, Leopold, (A) to **(M)**
Ward, Alvis A., (A) to **(M)**
Whitman, Vernon E., (A) to **(M)**
Wight, Ralph, (A) to **(M)**
William, Eric, (A) to **(M)**
Winn, Curtis B., (A) to **(M)**
Wolff, Joe M., (A) to **(M)**
Wutke, Louis, M., (A) to **(M)**

Chemical Corner

Edited by Irving M. Ewig for the Society's Laboratory Practice Committee. Suggestions should be sent to Society headquarters marked for the attention of Mr. Ewig. Neither the Society nor the Editor assumes any responsibility for the validity of the statements contained in this column. They are intended as suggestions for further investigation by interested persons.

Chemical Treatment Produces an Oil-Retaining Rust-Resistant Surface The Octagon Process, Inc., 15 Bank St., Staten Island, N.Y., markets a chemical preparation "Rustshield," which is a phosphatizing compound that imparts to a steel or iron surface a rust-resistant, highly absorbent quality thereby greatly increasing its oil-retention properties. The surface needs less lubrication and remains rust-free longer.

Increasing Emulsion Speed In an article by L. Jacobs, Jr., in *U.S. Camera, 14:* 41–3, March 1951, a new chemical called "Hydram" is described as increasing negative emulsion speed as much as ten times. Hydram is intended for use with conventional developers. The effect of this chemical is not to increase the threshold speed values but to increase the contrast in the toe part of the H&D curve. Hydram is not recommended when the developer contains sodium bisulfite, potassium metabisulfite, tartaric or citric acid.

Add More Life to Your Hypo *The British Journal of Photography, 98:* 191–92, April 1951, contains an article which has various suggestions for increasing fixer longevity: (1) use of an acid short stop; (2) use of a two-bath fixer arrangement; (3) removal of silver by some suitable means and replenishing the various chemicals which have been depleted; and (4) the addition of ammonium sulfate to the fixer. Ammonium sulfate imparts to a fixer increased fixing speed and longer life. Various formulas are also discussed.

New Plastic Sheeting A transparent plastic sheeting manufactured by The Alsynite Co. of America, 4670 DeSoto St., San Diego, Calif., may have applications in the laboratory or on the lot. This plastic is shatterproof, eliminates glare by light diffusion, is fire resistant, reduces heat transmission, has a high impact and load strength, is light in weight and is easy to install. It comes in flat panels and various colors. The sheet may be handled just like wood with a saw, nails or drill. Alsynite says that it is an improved substitute for glass.

Dispensing of Liquid From Carboys and Demijohns Greatly Simplified L. B. Russell Chemicals, Inc., 60 Orange St., Bloomfield, N.J., sell a small inexpensive ($15.50) hand-operated dispenser which fits into the mouth of carboys and demijohns of any type. Heavy carboys do not have to be rocked or tilted. The mere pressing of the bulb of the gadget dispenses the liquid from the carboy and the hazard and odor of splashing liquids are avoided. This device is made of acid-resistant plastic and fits all the way down to the bottom of the container so that all the liquid may be drawn off.

Liquid Stainless Steel The Lockrey-Frater Corp., 38–13 Tenth St., Long Island City, N.Y., may have the inexpensive answer to the laboratory's problem of protecting and decorating equipment with their "Liquid Stainless Steel." This is a paint-like material which is a suspension of finely divided actual stainless steel combined with a vinyl plastic. The liquid when applied will dry fairly rapidly and leave a coat of stainless steel on wood, metals, composition board, concrete, brick, etc.

It gives the appearance and much of the permanence of the metal itself. The coating offers the impermeability to moisture that 302 stainless steel does by an overlapping and interlocking of the flakes as they dry. Liquid Stainless Steel may be applied by spray, brush, or dip and gives a permanent coating in the bluish-gray, non-shining cast of stainless steel.

How to Get Better Film Washing BFI #20, a proprietary formula of The Brown Forman Industries, 1908 Howard St., Louisville, Ky., is claimed to increase washing efficiency and to reduce to one-twentieth the amount of hypo remaining in the film which would be there if washed with water. One gallon of BFI #20 will treat 36,000 ft of 35mm film.

Meetings

The Central Section of the SMPTE has scheduled two papers for its meeting at the Bell & Howell Co., 7100 McCormick Blvd., Chicago, on March 27. Bruno G. Staffen, development engineer of the Jensen Manufacturing Co., will describe a new low-cost theater speaker system, and there will be a description of the new Bell & Howell magnetic and optical 16mm sound projector by J. B. Weber, H. H. Brauer, F. J. Schussler and M. G. Townsley. C. E. Heppberger is Central Section Chairman, and John S. Powers is Program Chairman.

The Atlantic Coast Section of the SMPTE will meet on April 16, 7:30 P.M., at the Henry Hudson Hotel, New York City, when Robert Dressler of Paramount Pictures Corp.'s Chromatic Television Laboratories will present a paper and a demonstration on electrooptic sound recording on film.

71st Semiannual Convention of the SMPTE, April 21–25, The Drake, Chicago

Other Societies

American Physical Society, Mar. 20–22, Columbus, Ohio

Optical Society of America, Mar. 20–22, Hotel Statler, New York

American Physical Society, May 1–3, Washington, D.C.

Acoustical Society of America, May 8–10, New York

American Institute of Electrical Engineers, Summer General Meeting, June 23–27, Hotel Nicollet, Minneapolis, Minn.

American Physical Society, June 30–July 3, Denver, Colo.

National Audio-Visual Association, Convention and Trade Show, Aug. 2–5, Hotel Sherman, Chicago

Photographic Society of America, Annual Convention, Aug. 12–16, Hotel New Yorker, New York

American Institute of Electrical Engineers, Pacific General Meeting, Aug. 19–22, Hotel Westward Ho, Phoenix, Ariz.

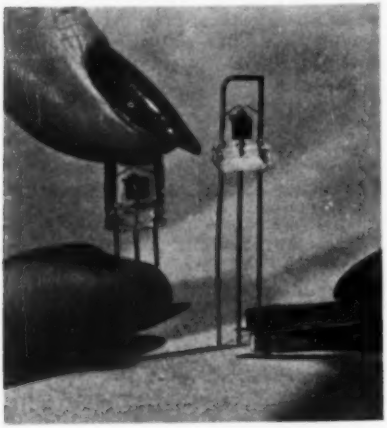
Illuminating Engineering Society, National Technical Conference, Aug. 27–30, Washington, D.C.

International Society of Photogrammetry, Conference, Sept. 4–13, Hotel Shoreham, Washington, D.C.

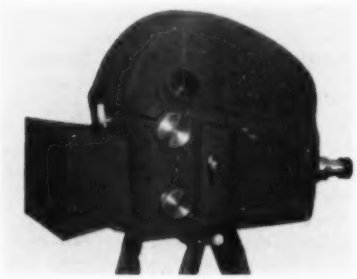
Test films are the customary tool for checking picture and sound performance in theaters, service shops, in factories and in television stations. Twenty-seven different test films in 16mm and 35mm sizes are produced by the Society and the Motion Picture Research Council. Write to Society Headquarters for a free catalog.

New Products

Further information about these items can be obtained direct from the addresses given. As in the case of technical papers, the Society is not responsible for manufacturers' statements, and publication of these items does not constitute endorsement of the products.



A developmental transistor was unveiled to the daily press during the last week of February, and the Camden, N.J., press department of RCA-Victor has released the accompanying photograph, which shows, in approximate life size, a transistor in an advanced stage of construction (right) and the finished transistor, with its components embedded in a protective casing of plastic (left). This transistor, based on the Bell Telephone Laboratories' development, is designed to perform many of the functions of a vacuum tube and can substitute for it in many applications. Because of its minute size and low power requirements, it is expected that it will make possible an important reduction in the size of many electronic devices used for television, radar and hearing aids.

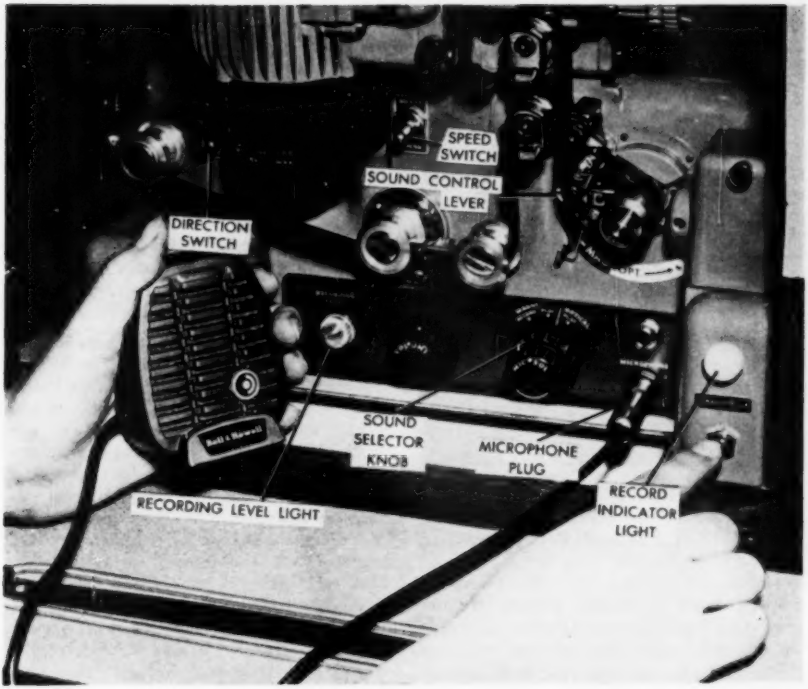


A light-weight sound-proof blimp for the Arriflex camera has been announced by Kadisch Camera & Sound Equipment Co., 128 West 48th St., New York 19, N.Y., manufacturer of the Arriflex. The blimp has an external control for follow-focus, and a built-in synchronous motor, and accepts 200- and 400-ft magazines. A new extension eyepiece through the blimp permits viewing through the lens during shooting. The new blimp is easily accessible for rapid changing of magazines.

The Berkshire Labstrobe, Model 18, has been designed as a small, light, economical stroboscope unit, using a standard neon bulb. It is available from the Berkshire Laboratories, 546 Beaver Pond Rd., Lincoln, Mass., with specifications:

Power source . . . . 115-v, 60-cycle, a-c
Power consumption . . . . less than 1 w
Flashing rate . . . . . 60 cycles/sec
(determined by line frequency)
Flash duration . . . . .approx. 100 μsec
(measured at 50% of peak intensity)
Net price, f.o.b. Lincoln, Mass . . $9.95

The manufacturers suggest that it will prove useful for determining the speeds of rotation of motors, machines, phonograph turntables and other objects. The instrument is housed in a chromium-plated case and is the same size as a standard two-cell flashlight.



The Bell & Howell Filmosound 202 16mm optical-magnetic recording projector is now being marketed to non-professionals to make possible movies with sound at a cost of $200 for a 10-min film. Bell & Howell particularly emphasizes the usefulness of such an assembly to small manufacturing or marketing companies which make use of training and sales films, to educational and church users, to those who wish to exhibit films in a number of languages or dialects (as in India), etc.

The Filmosound magnetically records, plays back and erases, while the film is being projected, on single perforated color or black-and-white film which has been magnetically striped. Bell & Howell says that their Soundstripe will outlast the film, may be re-recorded indefinitely, and may be economically applied to the film at a cost of 3½¢ a foot. The Filmosound, which costs $699 with a 6-in. speaker contained in the case, operates for recording at either 16 or 24 frames/sec. A 12-in. auxiliary speaker is also available. Although the sound quality is better at 24 frames/sec, Bell & Howell reports that either gives acceptable results, equal to or better than commercially available disc recordings.

Soundstripe, which is a magnetic iron oxide stripe, may be striped over the full sound track area of single-perforated film; thus silent movies taken or duplicated on single-perforated film or optical sound film with obsolete sound tracks can be treated with full Soundstripe. Or half the sound track on optical film may be processed with the magnetic stripe, thus making it possible to record and play back the magnetic track or play back the optical sound track.

The Utility Television Monitor Model CA16 is now being produced by Conrac, Inc., 19217 East Foothill Blvd., Glendora, Calif. This monitor has been designed for general purpose use by television studios, both in control rooms and on stage, with these specifications reported: a fully rectangular picture presentation of 9 in. × 12 in. on the 16GP4 kinescope; wide-band video amplifier with a smooth roll-off above 7 mc; and a total of 14 tubes in addition to the kinescope.

Design features planned for the convenience of operating personnel are: coaxial input connectors and a switch to select either composite video, or separate video and composite sync; both inputs equipped with parallel receptacles for multiple connection; heavy-gauge steel cabinet housing with carrying handles; and a removable front to facilitate cleaning the kinescope face and the protecting safety glass.

The 1952 Catalog of Films From Britain is now available upon request to British Information Services, 30 Rockefeller Plaza, New York 20, N.Y. Nearly 300 16mm sound films are described. These are available as rentals or purchases from regional British Information Services offices and some dealers. In addition to a descriptive listing of all general and specialized films, the British Information Services reports that the special section "The Motion Picture—The Art and Its Artists (Experimental and Classic Documentaries, including Academy Award Winners)" was added in response to the requests of the many film societies, colleges and universities.

Six American Standards have been added to the Motion Picture Set of 60 which the Society has had available for sale. To holders of the present set the Society has made available the six new standards: PH22.11-1952, PH22.24-1952, PH22.73-1951, PH22.74-1951, PH22.76-1951 and PH22.82-1951. The price is $1 plus 3% sales tax on deliveries in New York City.

The new set of 66 standards in a heavy three-post binder with an index is available at $14.50 plus 3% sales tax on deliveries in New York City; foreign postage is $.50 extra.

All standards **in sets only** are available from Society Headquarters. Single copies of any particular standard must be ordered from the American Standards Association, 70 East 45th St., New York 17, N.Y.

Back issues of the Journal available: Don Canady, 5125 Myerdale Drive, R.R. 15, Cincinnati 36, Ohio, desires to dispose of a complete set, in excellent condition, from January 1930 to date, plus one issue of September 1928. Anyone interested in acquiring the complete set should communicate directly with Mr. Canady.

SMPTE Officers and Committees: A new roster of Society Officers and the Committee Chairmen and Members will be published in the April *Journal*.

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